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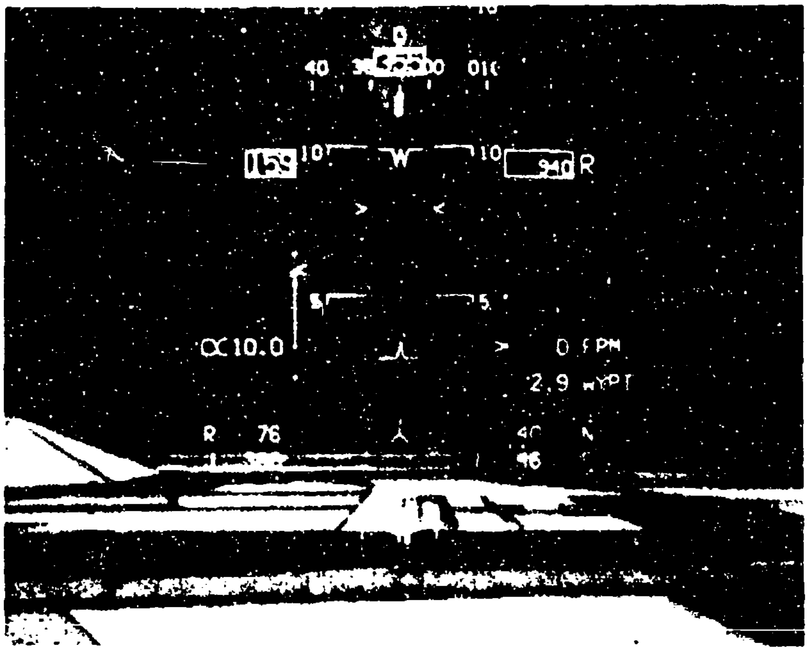

AD-A150 044

AIRCREW DISPLAY SYMPOSIUM PROCEEDINGS

15 AND 16 MAY 1984

AT

THE NAVAL AIR TEST CENTER
PATUXENT RIVER, MARYLAND

84 11 28 017

PROGRAM CHAIRMAN

MR. FREDRICK HOERNER

TECHNICAL ADVISOR

MR. LEE FIELD

ADMINISTRATOR

TERESA BOBBITT

SPONSOR

MR. WILLIAM KING

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A Systematic Program for the Development and Evaluation of Airborne Color Display Systems

Louis D. Silverstein
General Physics Corporation

Robin M. Merrifield and Wayne D. Smith
Boeing Commercial Airplane Company

Fredrick C. Hoerner
Naval Air Test Center

Sixth Advanced Aircrew Display Symposium
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INTRODUCTION

Major advances in color display technology have been evident during the past several years. These advances have been accompanied by a heightened awareness of color-related human factors issues. The recent proliferation of new color display applications can ~~thus~~ be traced to two interrelated trends: 1) a growing interest in the potential advantages of a color information display for enhancing human performance in complex man-machine systems; and 2) the availability of a rapidly evolving display technology to support advanced color display concepts.

The translation of color capability into an operational performance advantage is both system- and task-specific. The color coding of displayed information, when applied correctly and systematically, offers the greatest potential for enhancing operator performance in complex, high-workload situations and in severe, dynamic operational environments. These conditions, however, impose stringent requirements on the design of both the color display system and human operator tasks. An obvious application of color display technology, which conforms to the operational task and environmental considerations noted above, is for airborne operations. Piloting and airborne command/control tasks involve complex, highly-dense forms of information, entail periodic episodes of high operator workload, and are often performed under sub-optimal environmental conditions.

It is not surprising that the aerospace and aviation communities have pursued the integration of color display technology into advanced airborne systems. However, it is perhaps ironic that the first major developments of flight-qualified, full-color electronic displays were initiated by the commercial and general aviation sectors of the industry. The first large-scale integration of full-color flight displays into a new generation of aircraft was undertaken by the Boeing Commercial Airplane Company. Figure 1 shows the advanced flight deck of the Boeing Model 757/767 commercial aircraft, which incorporates six full-color, high-resolution shadow mask color CRT displays. The color displays are the foundation and primary pilot interface of two major systems on the 757/767. The Electronic Flight Instrument System (EFIS) consists of electronic ADI and HSI primary flight instruments. A second system, also composed of two displays, combines centrally-located Engine Indication and Crew Alerting functions (EICAS). Figure 2 shows typical enroute display formats for the EADI and EHSI components.

It has now been nearly two years since the Boeing Model 767 received flight certification by the Federal Aviation Administration, with t Model 757 aircraft following close behind. By any standards, the first generation of full-color flight displays have been an enormous success, receiving virtually unanimous acclaim by the technical engineering and pilot communities. Complimentary commerical programs in Europe have also been successful, leading to the development and certification of an advanced color-CRT-based flight deck for the Airbus Model A310. A number of commercial programs involving the retro-fit of electronic color displays into existing flight decks are currently in progress. In addition, experimental color display development and evaluation projects, such as the Advanced Flight Deck project which uses a BAC 1-11 aircraft as a test platform, have been ongoing for several years.

Significant advances have also been made in the general aviation market, where full-color electronic flight displays are currently offered as options to the avionics complement of small aircraft. An integrated avionics package, incorporating multiple electronic color displays, is now being developed for the latest version of the Gulfstream IV corporate jet aircraft.

The successful development and integration of full-color, shadow-mask display technology in commercial and general aviation aircraft have prompted a resurgence of interest in airborne military applications. Despite some previous experimental test and evaluation programs involving color display concepts for use in military systems, the first full-color electronic displays developed for airborne military operations in production aircraft are only now on the horizon. Several color systems are currently in the development or prototype phases and include both front cockpit and airborne command/control applications. Cockpit displays employing shadow-mask color CRTs are now being developed for the F-15 fighter aircraft (see Turner & Waruszewski, 1984) and at least one military transport. Full-color airborne command/control displays are being developed for retro-fit and integration with existing monitoring systems in P-3 and AWACS aircraft.

In the future, it appears likely that color display technology will be a part of most new developments in manned airborne systems (Waruszewski, 1981). Color offers the potential for greatly increasing information coding flexibility and capability, and for reducing visual search time on highly-dense complex displays. This increased flexibility and capability will in turn enable the development of more integrated and veridical forms

of information display, such as the pictorial display formats currently being developed and evaluated in a program sponsored by the Air Force Flight Dynamics Laboratory (Reising, 1984). The ultimate goal of all advanced color display development programs is increased system effectiveness via enhanced performance of the human operator.

While it is easy to state a goal of increased system effectiveness, defining the necessary steps to achieve that goal or the methods to evaluate the success of a particular color display application are difficult. Advances in color display technology have been rapid and are sure to continue. Our knowledge of how the human operator perceives, processes, and operates on color-coded information has improved accordingly. The development and evaluation of effective color display systems must be based upon an integrated approach which accounts for both human operator characteristics and color display system characteristics. A coherent, unified body of knowledge which dictates a generic color display design strategy or leads to meaningful design guidelines does not yet exist. Moreover, the goal of increased aircrew system effectiveness via enhanced operator performance requires a carefully planned strategic program of color display design, implementation, and evaluation.

A systematic program for the development and evaluation of airborne color display systems has recently been initiated by the Systems Engineering Test Directorate of the Naval Air Test Center (NATC), with cooperative support from the Federal Aviation Administration. The remainder of this paper describes the overall architecture of the program, details the objectives and approach for current program activities, and focuses on a few select issues of interest for color display system design.

PROGRAM OVERVIEW

The current program plan for NATC sponsored color display development and evaluation activities is presented in flowchart format in Figure 3. The program is structured according to three major program phases. Since our ultimate goal is to increase aircrew system effectiveness by enhancing human operator performance, the program structure is essentially "human factors driven" and can be mapped onto a hierarchical human factors analysis for color display systems (Silverstein, in press; Silverstein & Merrifield, 1981) as shown in Figure 4.

Phase I of the program focuses on fundamental visual, perceptual, and display system considerations. Color display design guidelines and recommendations are developed as they relate to human visual and perceptual functions. Display system hardware characteristics and measurement/specification techniques for critical color display parameters are described. The initial program phase also identifies unresolved issues and future color display research requirements. The emphasis of Phase II is on the application of color information coding to a variety of airborne display systems, and the definition of test and evalution requirements for color display systems hardware and color-coded display formats. The final phase of the program, Phase III, is logically defined as the mechanism for the conduct of display performance evaluation. In this last part of the program, detailed test plans are developed, operational performance evaluations of color display system hardware and coded information formats are conducted, pilot/operator primary task performance is analyzed and the workload impact of new display concepts is assessed, and finally required modifications or improvements to display hardware and/or information formats are documented.

Currently, we are approaching the completion of Phase I of the program. We have selected the F/A-18 and its complement of electronic displays as our initial working model, and are just beginning to configure a preliminary F/A-18 panel mock-up using Rockwell-Collins (757/767) shadow-mask color CRT display systems. Symbol generator software for this preliminary mock-up, to be used for F/A-18 color display concept demonstrations and early static coding/format evaluations, is now being developed.

Considering that we are just now completing Phase I of the program, it is appropriate to describe the scope of Phase I activities in somewhat more detail.

PROGRAM PHASE I DESCRIPTION

The initial phase of the program has been sub-divided into two major tasks. The specific objectives and goals for each Phase I task are as follows:

- Task 1 - Review and integration of the current philosphy and standards on the application of color in electronic display systems
  - Emphasis on the impact of color on display visual parameters
  - Issues, recommendations, and guidelines for color display operational

effectiveness

- o Task 2 - Survey of currently available color display systems
  - Review existing system capabilities
  - Relate functional capabilities of available systems to philosophy and applications standards
  - Predict future trends and developments

A large amount of information has been assembled and integrated in order to satisfy the objectives of the first task of the program. Therefore, a further break-down of the topics within Task 1 will reveal more of the underlying contents and strategy of this effort. The following list of subtasks provides an organization according to four major content areas:

- o Subtask 1 - Principal factors determining color display effectiveness
- o Subtask 2 - Impact of the operational environment on color display requirements and the use of color as an information coding dimension
- o Subtask 3 - Color display specification, measurement, and calibration techniques
- o Subtask 4 - Unresolved issues and future research requirements

The subtasks listed above can in turn be documented with more meaningful descriptors to provide a more comprehensive overview of Phase I:

- o Subtask 1 - Principal factors determining color display effectiveness
  - o Review and analysis of visual/perceptual issues and their impact on color display characteristics
    - Human operator and display systems requirements analyzed according to common functional units
      - color domain
      - intensity domain
      - temporal domain
      - spatial domain
    - Provide recommendations and guidelines where sufficient support

data exist

- Identify analytical and experimental techniques useful for developing and/or verifying system specifications
- Indicate data voids and offer qualified recommendations

o Subtask 2 - Impact of the operational environment on color display requirements and the use of color as an information coding dimension

o Identify critical environmental variables and discuss their impact on visual/perceptual performance and color display characteristics
  - Ambient illumination (color temperature and intensity)
    - analytical color modeling techniques
    - experimental test methods for display parameter verification
    - compensation characteristics for automatic display brightness/contrast control systems
  - Vibration
    - effects on image quality and visual performance
    - effects on display structures

o Provide recommendations and guidelines where sufficient support data exist

o Subtask 3 - Color display specification, measurement, and calibration techniques

o Identify, define, and review primary color display system visual parameters
  - resolution
  - linewidth/spot size
    - maximum
    - minimum
  - video bandwidth
  - beam focus
  - convergence
  - luminance and contrast
    - maximum
    - minimum
    - uniformity

- filters
- Frame/field refresh rates
- Chromaticity
  - color repertoire
  - color difference
  - chromaticity tolerance
- o Develop display specification guidelines
  - Generic specifications for airborne color display system visual parameters
- o Review color display measurement issues
  - Identify appropriate measurement and calibration techniques

o Subtask 4 - Unresolved issues and future color display research requirements

- o Identify major data voids and their significance for color display system design
  - visual/perceptual factors
  - color display hardware characteristics
- o Prioritize unresolved issues in terms of current needs
- o Recommend types of future research and structure of data which would most efficiently resolve problems areas

As stated previously, the objectives of the second task of the initial phase of the program are concerned with the survey and evaluation of currently available or proposed color display systems. Task II has been organized according to the following three sub-tasks:

- o Subtask 1 - Technical evaluation of hardware characteristics and visual parameters
- o Subtask 2 - Evaluation summary and specific recommendations
- o Subtask 3 - Prediction of future trends and developments in color display technology

A survey of the state-of-the-art in color CRT display systems which are either available or under development was conducted from November 1983 through April 1984. Twelve companies which comprise a representative sampling of high technology color CRT display equipment manufacturers were surveyed. From these companies and their inputs

twenty systems have been evaluated and parametrically described.

The color CRT display systems evaluated fall into three general categories - front cockpit color CRT displays, work station displays, and laboratory monitors. Front cockpit displays are those designed for intended use in high ambient light environments such as transport aircraft cockpits (8,000 ft-c ambient) and fighter aircraft cockpits with bubble canopies (10,000 ft-c ambient). Work station displays are those designed for controlled ambient lighting environments such as command/control stations. Work station displays are typically larger and have significantly lower luminance requirements than front cockpit displays. Laboratory monitors are displays specifically designed for use in laboratory environments and are not intended for airborne applications. Three such systems were surveyed due to their special features such as high bandwidth, superior color tracking, or unique convergence methods. In order to facilitate comparisons between systems and help identify common limitations of the current technology, the same basic set of physical, resolution, luminance, and chromaticity parameters were used to define the visual performance characteristics of all surveyed systems.

Taken together, the two tasks of program Phase I are intended to provide a comprehensive, state-of-the-art overview of fundamental visual, perceptual, and display system considerations for airborne applications of color display technology. The following sections focus on a few select issues of interest for color display system design.

A FEW INTERESTING ISSUES

PREDICTIVE COLOR MODELING FOR SMALL COLOR IMAGES

The CIE (1931) chromaticity system and diagram, illustrated in Figure 5, enables basic colorimetric description and manipulation for electronic displays. However, the prediction and optimization of effective color display performance requires an analytical method which characterizes the perceptual interface between color display and observer (Silverstein & Merrifield, 1981). Complex multi-color display formats, as well as the extreme dynamic range of ambient lighting conditions in the airborne environment, pose difficult problems for the prediction of color display performance. Existing analytic methods are limited in their precision, for the human visual systems is far from being solved. Nevertheless, the development and continuous refinement of predictive color modeling techniques is necessary in order to minimize the need for repetitive and

expensive color display performance testing. Predictive analytical methods are integral to a number of critical issues in the development of color displays: color repertoire selection; assessment of the impact of the operational environment: specification of color production methods; color control and tolerance; and definition of essential conditions for display performance verification testing.

Currently, the CIE recommends the use of CIELUV for predicting the perceptibility of color differences in cases where colored lights are additively mixed. The electronic color display is obviously one such case. CIELUV consists of the most recent (CIE-1976) uniform chromaticity scale (UCS) diagram with associated color difference equations (CIE Publication No. 15-Supplement 2, 1978). The 1976 UCS diagram, shown in Figure 6, is basically a simple transformation of a previous 1960 UCS color space in which the v-axis of the diagram has been magnified by a factor of 1.5. Re-scaling of the v-axis in the 1976 UCS diagram corrects for underestimated sensitivity of the violet-green yellow component of chromatic perception. Figure 7 presents a graphic comparison of the 1960 and 1976 UCS color spaces. An examination of Figure 8 (adapted from Laycock & Viveash, 1972), reveals that the color discrimination elipses of MacAdam and Stiles (see Wyszecki & Stiles, 1967) become nearly circular and achieve a reasonable uniformity in the 1976 UCS color space, indicating an improvement in perceptual uniformity over previous attempts to derive a uniform color space.

In addition to the 1976 UCS color space, CIELUV contains a set of color difference equations. The total color difference between two color samples, derived in complete detail in Figures 9 and 10, is basically stated as follows:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta U^*)^2 + (\Delta V^*)^2]^{1/2},$$

where

$$L^* = 116\,(Y/Yn)^{1/3} - 16,\ Y/Yn > 0.01,$$

$$U^* = 13\,L^*\,(u' - u'_n),$$

$$V^* = 13\,L^*\,(v' - v'_n),$$

$$u' = 4X/(X + 15Y + 3Z) \text{ or } 4x/-2x + 12y + 3,$$

$$v' = 9Y/(X + 15Y + 3Z) \text{ or } 9y/-2x + 12y + 3,$$

The variable reference coordinates (u'_n,v'_n) and reference luminance level (Y_n) refer to the neutral point of the three-dimensional coordinate system, and for surface-color applications are typically taken to be the characteristics of the surface illuminant (i.e. a

white object-color stimulus). By convention, the chromaticity of CIE standard illuminant D65 is often used (u'_n = 0.1978, v'_n = 0.4684) with Y_n set equal to 100. It should be noted that Y_n is actually a scaling or normalizing factor, and for surface applications Y_n = 100 denotes the luminance of the maximum possible reflectance of the surface under the illuminant used (i.e. 100%). Recently, Carter and Carter (1983) have raised the issue concerning the appropriate reference or neutral point when CIELUV is used for estimating color difference with self-luminous sources such as electronic display media. The parameters (u'_n, v'_n) and Y_n have no obvious counterparts for self-luminous sources. Moreover, the arbitrary usage of Y_n = 100 will result in an invariance in ΔE^* units depending on the units of luminance used in computing ΔE^*. Carter and Carter (1983) have recommended that the 1976 UCS coordinates of D65 (u'_n = 0.1978, v'_n = 0.4684) be utilized as the neutral chromatic points and that Y_n should be set to the maximum possible luminance of the images whose color difference (ΔE^*) is to be estimated. While this solution is not entirely satisfactory, it does preserve ΔE^* scale invariance with respect to the choice of luminance units and provides an acceptable interim recommendation. The choice of appropriate neutral reference values for color difference formulations to be used with self-luminous color displays will be a priority topic for a newly formed CIE committee on revised standards for self-luminous displays (personal communication, Dr. J. J. Rennilson, January 20, 1984).

The CIELUV color-difference equations have come into relatively wide-spread usage as a a basic tool for the design of self-luminous color displays (Carter & Carter, 1981, 1982, 1983; Lippert, Farley, Post, & Snyder, 1983; Merrifield, in press; Murch, Cranford, & McManus, 1983; Silverstein, in press; Snyder, 1982). Carter and Carter (1981) have found that CIELUV color difference is a good predictor of visual search performance in color-coded displays, and they have developed a computer-based algorithm for selecting sets of high-contrast colors using a CIELUV metric (Carter & Carter, 1982). Laycock and Viveash (1982) have found that the 1976 UCS space and CIELUV color-difference equations provide the most appropriate foundation for color display specification and modeling. Murch et. al. (1983) noted that the CIELUV color-difference formulas are good predictors of color and brightness contrast for color CRT displays. Snyder and his students (Lippert et. al., 1983; Post, Costanza, & Lippert, 1982: Snyder, 1982) have come to similar conclusions, although some non-linearities and problems of scaling of the luminance axis of the CIELUV model have been discovered. The significance of such anomalies is currently unclear. While future research will undoubtedly bring refinements to the CIELUV model, including a more optimal scaling of the luminance axis, the CIE

1976 UCS color space and CIELUV equations currently offer the most empirically sound foundation of predicting effective color display performance.

A graphic representation of CIELUV color difference within a three-dimensional rectangular coordinate system is shown in Figure 10. The basic application of CIELUV for estimating color difference on an electronic color display is relatively straightforward and is illustrated in Figure 11.

While the CIELUV system is an extremely useful tool for the display designer, the accuracy of CIELUV color-difference predictions are still limited by factors not contained in the basic system. Two such factors of major magnitude are color image field size and an appropriate spectral luminosity function for heterochromatic images.

It is a well-known fact of color perception that the ability to perceive color differences is profoundly influenced by the field size of the colored images to be compared (Burnham & Newhall, 1953; Burnham, Hanes, & Bartleson, 1963; Judd & Wyszecki, 1963). In general, small color fields appear less saturated and sometimes appear shifted in hue relative to larger targets of the same measured chromaticity and luminance. The ability to discriminate between colors, particularly along the blue-yellow continuum, is also reduced for small fields. Since displayed image sizes for color display systems will often be much smaller than the two degree or ten degree standard observer data which form the basis of current predictive color models, sizeable errors in estimated color difference can result (Silverstein, in press; Silverstein & Merrifield, 1981; Ward, Greene, & Martin, 1983). A considerable increase in precision for current color models could be achieved if estimates of field size effects were incorporated into color difference equations.

To a large extent, symbol sizes for alphanumeric and graphic symbols on color information displays will subtend less than thirty minutes of visual arc. Fortunately, Judd and his colleagues (Judd & Yonemura, 1969; Judd & Eastman, 1971) have worked out an empirically-derived set of small-field correction factors for the 1964 CIE (U*, V*, W*) color-difference metric, a predecessor of the CIELUV system which was based on the CIE 1960 UCS color space. The correction assumes three weighting factors k_u, k_v, and k_W which represent the relationship between field size angular subtense and the sensitivity of the red-green, violet-green yellow, and light-dark visual channels, respectively (Judd & Yonemura, 1969). The dependency of each of these factors on angular subtense is shown in Figure 12.

It is important to note that the chromatic weighting factors, k_u and k_v, decrease rapidly with reductions in angular subtense compared to the light-dark factor, k_w. This accords well with other visual data indicating a greater dependency between field size and chromatic perception than between field size and brightness perception. In addition, the extremely rapid decrement in k_v as angular subtense is decreased agrees well with the phenomenon of small field tritanopia, particularly severe losses in violet-yellow sensitivity for field sizes below about twenty arc minutes (e.g., Farrell & Booth, 1975).

In order to apply these correction factors to the CIELUV color space, it becomes necessary to modify the violet-yellow factor, k_v. Since the major difference between the 1964 CIE (U*, V*, W*) color space and the CIELUV color space may be found in a 1.5x expansion of the v-axis in the 1976 CIE UCS diagram, it becomes necessary to divide the violet-yellow factor, k_v, by 1.5 to account for the enhanced sensitivity of the v-axis in CIELUV. Figure 13 shows the appropriate small-field correction factors (k_u', k_v', k_L) for the CIELUV color difference equations.

A preliminary evaluation of the sensitivity of the CIELUV small field correction factors can be obtained by a re-analysis of the results from a set of studies by Silverstein and Merrifield (1981). These studies involved the specification and visual verification of color and luminance requirements for the shadow-mask color CRTs used in the Boeing Model 757/767 aircraft. The objective was to develop an effective color repertoire for use in ambient environments ranging from .1 ft-c to 8000 ft-c. Operational display formats were to consist of raster background fields up to 5.5 degrees of visual arc and varied stroke-written symbols of small angular subtense. In the initial step, a preliminary color repertoire was developed through analytical techniques. A computer color model was used to facilitate the attempt to maximize the perceptual dispersion between colors, within the constraints imposed by the display hardware. The initial color set contained seven stroke colors, four of which were also used for the larger raster fields.

Visual testing to verify and/or modify the selected colors and to determine luminance requirements was conducted in three phases. Pilots and engineering personnel served as subjects and were all screened for color vision deficiencies. The visual task employed a comparative forced-choice, color-naming task which best represented the partially

redundant use of color coding on the operational flight displays[1]. A criterion of 95% correct color discrimination for each color was adopted as acceptable.

In the first test phase, raster chromaticity and luminance requirements for 5.5 degree raster fields of red, green, amber and cyan were determined. Testing was conducted under simulated sunlight viewing conditions which for the particular displays under consideration was estimated at 8000 ft-c. The second test phase, also conducted under 8000 ft-c. of ambient illumination, was designed to determine chrominance and luminance requirements for seven stroke-written symbol colors. Diamond-shaped symbols of approximately 20 minutes of visual arc were used as targets and were presented on either a blank background or a background consisting of one of the raster colors specified in the first test phase. Raster luminance was fixed at previously determined levels and stroke symbol luminance was manipulated in increments of stroke/raster contrast ratio. Figure 14 illustrates the locations of the seven stroke colors in CIE 1931 coordinates and the directional shifts in chromaticity due to ambient illumination of the display. Figure 15 shows the test pattern generated on the CRT display as well as a summary of test conditions. The basic test results for the second test phase are shown in Figure 16. Color discrimination performance increased up to a stroke/raster contrast ratio of approximately 5.0, but beyond that point additional increments in stroke luminance offered no significant improvements in performance. Figure 16 also reveals that criterion performance for the seven colors was not reached simultaneously. During the last phase of test, criterion color discrimination performance at a stroke/raster contrast ratio of 5.0 was verified under low-ambient viewing conditions (.1 ft-c.)

A careful examination of Figure 16 indicates that the colors magenta, purple, cyan, and white failed to achieve criterion color discermination performance at a stroke/raster contrast ratio of 4.0. Thus, all of the secondary display colors containing some mixture of the blue primary were the most difficult to discriminate, and this subset of colors was responsible for "driving up" display luminance levels to a stroke/raster contrast ratio of 5.0. Beyond a stroke/raster contrast ratio of 5.0 all display colors meet or exceed the

[1]It should be noted that color is never used as a singular information code on the 757/767 flight displays. Rather, color is always combined with shape or positional coding of symbology to produce a highly reliable, partially redundant form of information coding.

95% performance criterion; however, a persistent pattern of errors (i.e., color confusions) occurred throughout the range of testing. Figure 17 shows the pattern of color confusions found at a stroke/raster contract ratio of 5.0. It can be seen that disproportionately higher errors occur between cyan and green, white and amber, red and magenta, and magenta and purple. The results of Figure 16 can thus be explained by the fact that ..st subjects tended to confuse cyan with green, white with amber, magenta with red, and purple with magenta. Evidently, discrimination between pairs of colors which differ predominantly in the amount of the blue primary component is a difficult task when the angular subtense of the images is small. The obtained pattern of color confusions is not unlike the tritanopic confusion trends often obtained with small chromatic images (Burnham & Newhall, 1953).

In addition to illustrating color discrimination errors, Figure 17 also shows the pattern of CIELUV color difference predictions (ΔE^*) between adjacent test colors and field-size corrected color difference estimates (ΔE^*_{sf}) computed using the 20 arc minute size of the test symbols. It is apparent that the uncorrected (ΔE^*) color difference estimates do not predict the obtained pattern of color discrimination performance. However, by application of the field-size correction (ΔE^*_{sf}) the color difference estimates can be made to correspond to the obtained results quite closely.

The incorporation of a field-size correction factor into existing predictive color models can enhance their utility as a color display design tool. Since many color display applications involve the presentation of small chromatic images, a more realistic and uniform description of the effective color performance of many electronic color display systems can be achieved by taking image size into consideration. Future empirical research will undoubtedly improve the precision of analytical color models.

DISCREPANCIES BETWEEN MEASURED LUMINANCE AND PERCEIVED BRIGHTNESS FOR MULTI-COLOR IMAGES

Modern electronic color display systems are currently being used for presentation of a broad range of information. Color coding can be used to convey unique information, increase information redundancy, organize a spatially complex display, highlight particular features of a presentation, and attract the attention of a busy operator. In some color applications, such as the coding of normal-advisory-caution-warning schemes, it may be desirable for simultaneously displayed colors to appear equally bright or in

some known ratio of perceived brightness. For many colors and viewing conditions, simple photometric luminance measurements will not satisfy these goals.

Inadequacies in the current photopic luminosity function V(λ) for estimating the brightness of chromatic sources have been noted for years (CIE Publication No. 41, 1978; Kinney, 1983). Basically, failures in the relationship between luminance and subjective brightness for chromatic visual sources can be traced to the fact that a non-additive luminous efficiency function describes the relative perceived brightness of simultaneous, heterochromatic samples. Kinney (1983) has pointed out that the presence or absence of additivity depends on the methods used to obtain the luminous efficiency functions. Further, the standard V(λ) photopic sensitivity curve was obtained by flicker photometry, which produces additive results, but the appropriate method for assessing the brightness of heterochromatic images is heterochromatic brightness matching, which yields non-additive results. The impact of this discrepancy is that the relative brightness of narrow-band chromatic images will be seriously underestimated at both short- and long-wavelengths. That is, blue and red images will appear much brighter than would be predicted by their measured luminance. The differences between estimates of luminous efficiency provided by the standard photopic luminosity function V(λ) present in all photometric measurement instruments and those obtained by heterochromatic brightness matching are illustrated in Figure 18.

Since the method of flicker photometry primarily samples the output of the achromatic visual channel, it follows that the standard photopic luminosity function (Vλ), being derived from this method, will yield luminance values which are most representative of the brightness of achromatic or low purity sources (CIE Publication 41, 1978). Thus, achromatic sources will appear equally bright when their luminances are equivalent as will colors of equal luminance which are close in wavelength. However, two highly saturated colors relatively far apart in wavelength and equal in luminance will rarely appear equally bright. The degree of chromaticness of a stimulus affects perceived brightness, and the perceived brightness of colors of high purity will depart more from measured luminance than colors of low purity. This relationship is illustrated in Figure 19 (from Kinney, 1983), in which spectral luminous efficiency is plotted as a function of color purity. The lowest curve represents V(λ), and it can be seen that as color purity is decreased or approaches neutrality (achromatic) the spectral luminous efficiency function comes progressively closer to matching V(λ), i.e. measured luminance.

Kinney (1983) has indicated that CIE Technical Committee 1.4 is presently working on new photometric standards which will be more applicable to self-luminous displays under a wide range of viewing conditions. To date, no new standard or replacement to the familiar V (λ) curve has been presented. However, two temporary solutions have been proposed for estimating the relative brightness of heterochromatic sources. Kinney (1983) has offered an interim solution for monochromatic or high-purity self-luminous sources which consists of a brightness/luminance (B/L) weighting function for wavelengths betweeen 400-730 nanometers. Figure 20 contains tabled values of spectral luminous efficiency determined by heterochromatic brightness matching and computed ratios between these values and V(λ) luminance weighting factors (B/L). It can be seen that these ratios become quite large at the ends of the spectrum. Kinney (1983) has recommended that the B/L ratios be used only for monochromatic or narrow-band sources. Thus, they should work reasonably well for such notably narrow-band self-luminous display media as light emitting diodes (LEDs), but it is questionnable whether color CRT phosphors represent a sufficiently pure self-luminous source for the B/L ratios of Kinney (1983) to apply. While P22 red and P22 blue phosphors in particular may achieve high values of excitation purity under low-ambient lighting conditions, P22 or P43 green primary phosphors are much less saturated and all CRT colors will undergo substantial reductions in excitation purity under the high-ambient lighting conditions found in the airborne operating environment (Merrifield, in press; Silverstein, in press; Silverstein & Merrifield, 1981).

Another interim solution recently proposed by Ware and Cowan (1983) has been submitted to the CIE for consideration as a provisional recommendation. In this approach, a luminance to brightness conversion is derived by finding the best fitting polynomial function relating the logarithm of B/L ratios taken from heterochromatic brightness matching data to CIE (1931) chromaticity coordinates (x, y). Since this approach is based upon chromaticity coordinates rather than wavelength, it may be used to estimate the relative brightness of chromatic sources which are not monochromatic or spectrally pure. Ware and Cowan (1983) have cautioned that their correction does not yield anything which relates to the absolute experience of brightness. Rather, its utility lies in the determination of the relative brightness of heterochromatic stimuli.

The solution proposed by Ware and Cowan (1983) has several important advantages: (1) the solution was determined statistically by finding the best-fitting polynomial expresssion for a large data base of results from heterochromatic brightness-matching

studies; (2) inputs to the solution are commonly used colorimetric and photometric quantities; and (3) unlike other proposed solutions (e.g., Kinney, 1983), the luminance to brightness correction may be estimated for chromatic sources which are not monochromatic or of very high excitation purity. This latter point is especially relevant to airborne applications since color displays operated within a variable range of illumination tend to be high purity chromatic sources at low illumination levels and low-purity chromatic sources at high illumination levels. In addition, as Kinney (1983) has pointed out and Ware and Cowan (1983) have effectively demonstrated with their correction factor (see Figure 21), the discrepancies between luminance and perceived brightness decrease as excitation purity decreases. The perceived brightness of chromatic sources of low excitation purity, such as color CRT phosphors desaturated by high ambient illumination, is reasonably well estimated by the photopic luminosity function (i.e., measured luminance).

Ware and Cowan's (1983) solution contains a polynomial correction factor and a brightness estimation formula which includes the correction factor as a term. The correction factor and brightness formula are described in Figure 22 and have been used to calculate estimated equal brightness values for the primaries of a particular shadow-mask color CRT. These calculations are illustrated in Figure 23. It can be see that for this particular display (under conditions of low ambient illumination) only 20.2 Ft-L of red and 15.8 Ft-L of blue are required to approximately match the apparent brightness of 30 Ft-L of the green system primary. These estimated luminance levels for equal perceived brightness are in reasonable accord with the results of a recent heterochromatic brightness matching study which used a shadow-mask color CRT display with P22 phosphors (Murch et. al. 1983), and also are in good agreement with our own observations of many color displays viewed in low-ambient settings. Under conditions of high ambient illumination, reductions in excitation purity of display colors shift the chromaticity coordinates of the colors toward a neutral point, and the resulting luminance to brightness estimates tend toward unity.

AUTOMATIC BRIGHTNESS/CONTRAST COMPENSATION SYSTEMS FOR DYNAMIC AMBIENT LIGHTING ENVIRONMENTS

Airborne color display systems for cockpit applications must be capable of providing suitable chromatic differentiation and image brightness over a broad dynamic range of ambient illumination. In addition, cockpit displays must also be able to accommodate

transient changes in the state of adaptation of the pilot's eyes. A condition of "eye adaptation mismatch" can occur when the eyes are adapted to a surround luminance much higher than that of the display or when the eyes sequentially alternate between a high-luminance outside view and relatively low-luminance display. Ambient illumination incident upon the surface of a panel-mounted display may be expected to range from approximately .1 to 8,000 ft-C in the enclosed flight deck of a large transport aircraft such as the Boeing 767 (Silverstein & Merrifield, 1981), while the range of incident ambient illumination is extended from approximately .1 to 10,000 ft-C for aircraft with high transmissibility bubble canopies (Rogers & Poplawski, 1973; Semple, Heapy, Conway, & Burnette, 1971). The range of forward-field-of-view (FFOV) adapting luminances is similar for the two environments and can be expected to range from approximately .0001 to 10,000 Ft-L (Rogers & Poplawski, 1973; Semple et. al., 1971).

In order to minimize the need for frequent manual adjustments of display luminance during dynamic changes in cockpit ambient illumination and FFOV luminance, some form of automatic compensation control must be incorporated into the display system. Historically, automatic brightness control systems have often been implemented by changing the display luminance as a function of the input from a panel-mounted light sensor in such a way that the contrast between emitted display luminance and display background luminance remains constant. This simplistic constant-contrast type of automatic control has not proven effective for two reasons: 1) display contrast requirements change dramatically as a function display background luminance (i.e. an observer's contrast sensitivity increases as background luminance increases - relatively high contrast is required at low levels of display background luminance while relatively low contrast is required at high levels of background luminance); and 2) the symbol-to-background contrast required for comfortable display readability varies for different eye adaptation levels. Failure to incorporate an automatic brightness control system or implementation of an inappropriate system often causes operators to drive the displays to a higher luminance level than required. This strategy minimizes the need for "nuisance" brightness adjustments during high-workload operations. Unfortunately, it also results in a reduction of the operational life of the display.

Recognizing the need for an effective automatic brightness control system, Boeing initiated a study program during the development of the 757/767 color display systems which concluded that three types of brightness control were required:

1) A manual brightness control to accommodate individual differences in the visual sensitivity of pilots as well as the use of sunglasses.

2) Automatic brightness compensation which changes the display luminance as a function of changing ambient light levels incident on the display (as detected by an internal light sensor integral to each display).

3) Automatic contrast compensation which changes the display symbol-to-background contrast as a function of changing luminance levels in the pilot's FFOV (as detected by a remote, forward facing light sensor)

In order to determine the appropriate functions for each type of control and the method for integrating the functions into a single, adaptive brightness control system, visual testing was conducted in an ambient light simulator which approximated the viewing geometry of the Boeing 767 flight deck. A diagram of this apparatus is shown in Figure 24. Fourteen test subjects were each exposed to a series of parametric combinations of intensity of incident ambient illumination and FFOV luminance. The experimental task consisted of alternating periods of monitoring the FFOV and test display, during which time subjects adjusted display luminance to provide comfortable viewing and display readability. The test display was an engineering prototype shadow-mask color CRT. A complex EADI format, which included all display colors, was continuously presented on the test display.

The results of this investigation can be expressed by two functions: one function relates reflected display background luminance produced by incident ambient illumination (total display reflectance = approximately 1.25%) to subject-selected levels of emitted display luminance while a second function describes the obtained relationship between the ratio of FFOV intensity to display white stroke intensity and a contrast multiple or gain factor determined from subjects manual brightness selection.

The first function, which relates display background luminance to emitted symbol luminance, is shown in Figure 25. Only the results for the colors white, green, and red are plotted since the functions for all colors were determined by a single brightness control. The relationship is described by a power function which becomes linear in logarithmic coordinates. The curve shown for the monochromatic CRT is adapted from a study by Knowles and Wulfeck (1972) which examined luminance and contrast

requirements for several high-contrast monochromatic CRTs. While the slopes of the functions for the color and monochromatic displays differ somewhat, they are both described by power functions, are in good agreement with the basic vision literature on brightness perception and brightness discrimination (Blackwell, 1946; Brown & Mueller, 1965; Graham, 1965), and depart significantly from a constant-contrast function. In addition, the data from the previously described study on small symbol visibility and color discrimination are plotted for comparison purposes, since it has generally been found that observers select higher display luminance levels for comfortable viewing than are actually required for minimum visual performance (Knowles & Wulfeck, 1972). This last issue provides some rationale for the argument that an effective automatic brightness control can help prolong display life by minimizing excessive manually-selected levels of display luminance.

The second function, which describes the relationship between the ratio of FFOV luminance to display peak intensity (i.e., white stroke intensity) and a contrast multiple or gain factor, is illustrated in Figure 26. This contrast multiple, in effect, compensates for conditions of transient adaptation or eye adaptation mismatch. From Figure 26, it is apparent that the obtained test results quite closely approximate the previously established correction function for monochromatic displays (see inset of Figure 26; adapted from Burnette, 1972), at least for the higher ratios of mis-adaptation. The test results for the color display dictated the necessity for an adapted gain function, which consists of a single-slope function following the high-ratio segment of the previously established monochromatic correction function but reaching a contrast multiple of unity at a FFOV/peak display intensity ratio of 4.2. The discrepancies between the low-ratio segments of present and previous correction functions may be explained by the fact that the denominators of the ratios which determine the two functions differ. Display white stroke intensity will always be higher than, but proportional to, display background luminance for a display with an acceptable level of contrast.

Figure 27 shows a functional block diagram of an automatic brightness/contrast compensation system which incorporates the functions derived from empirical vision testing with a prototype color display. In addition to the implementation of these basic functions, the system incorporates a manual brightness control with a logarithmic characteristic and separate time constants for commanded display brightness increments and decrements. A logarithmic manual control is required since greater adjustment sensitivity is needed at low brightness levels than at higher levels. The time constants

smooth the system response and tailor display brightness transitions to approximate the time course of changing visual sensitivity and instantaneous operational contrast requirements. Thus, a short time constant is required for brightness increments (e.g. 1 second) while a relatively long time constant (e.g. 60 seconds) is required for brightness decrements. The time constants do not filter the action of manual brightness adjustments.

Figure 28 reveals the response characteristics of the automatic compensation system. The manual brightness control serves to set the "bias" on the system according to an individual operator's visual sensitivity and can also compensate for the use of sunglasses or sun visors. Once the system "bias" is set, the control functions are designed to maintain adequate display brightness and contrast across a broad range of illumination and adaptation conditions without the need for further manual adjustment. Under very low ambient conditions, when the display operator is undergoing continuous dark adaptation, small manual adjustments in display brightness are generally required.

An automatic brightness/contrast compensation system conforming to the basic characteristics discussed in this paper has received extensive operational validation during both flight test and line service of the Boeing Model 757/767 aircraft.

Airborne color display systems are being considered for a variety of cockpit applications in military aircraft. Effective automatic brightness/contrast compensation systems will be required to maintain acceptable chromatic differentiation and image brightness without the penalty of frequent manual display brightness adjustments during high-workload operations. Refinements and modifications of the automatic compensation system described in this paper will undoubtedly be necessary to meet the diverse requirements of varied cockpit environments and color display applications. Nevertheless, the basic system architecture and validated control functions provide a model for the design of future airborne color displays.

OVERVIEW AND CONCLUSIONS

The successful development and integration of full-color, shadow-mask display technology in commercial and general aviation aircraft have prompted a resurgence of interest in airborne military applications. Military color display systems for both cockpit and command/control applications are now on the horizon. In the future, it appears

likely that color display technology will be a part of most new developments in manned airborne systems.

Color offers the potential for greatly increasing information coding flexibility and capability, and for reducing visual search time on highly-dense complex displays. This increased flexibility and capability will in turn enable the development of more integrated and veridical forms of information display. However, the translation of color capability into an operational performance advantage is both system and task specific. The color coding of displayed information, when applied correctly and systematically, offer the greatest potential for enhancing operator performance in complex, high-workload situations and in severe, dynamic operational environments. These conditions impose stringent requirements on the design of both the color display system and human operator tasks.

The ultimate goal of all advanced color display development programs is increased system effectiveness via enhanced performance of the human operator. While it is easy to state a goal of increased system effectiveness, defining the necessary steps to achieve that goal or the methods to evaluate the success of a particular color display application are difficult. Advances in color display technology have been rapid and are sure to continue. Our knowledge of how the human operator perceives, processes and operates on color-coded information has improved accordingly. The development and evaluation of effective color display systems must be based upon an integrated approach which accounts for both human operator characteristics and color display system characteristics.

A coherent, unified body of knowledge which dictates a generic color display design strategy or leads to meaningful design guidelines does not yet exist. Moreover, the goal of increased aircrew system effectiveness via enhanced operator performance requires a carefully planned strategic program of color display design, implementation, and evaluation. In recognition of these current needs, the Systems Engineering Test Directorate of the Naval Air Test Center, in cooperation with the Federal Aviation Administration, has recently initiated a systematic program for the development and evaluation of airborne color display systems.

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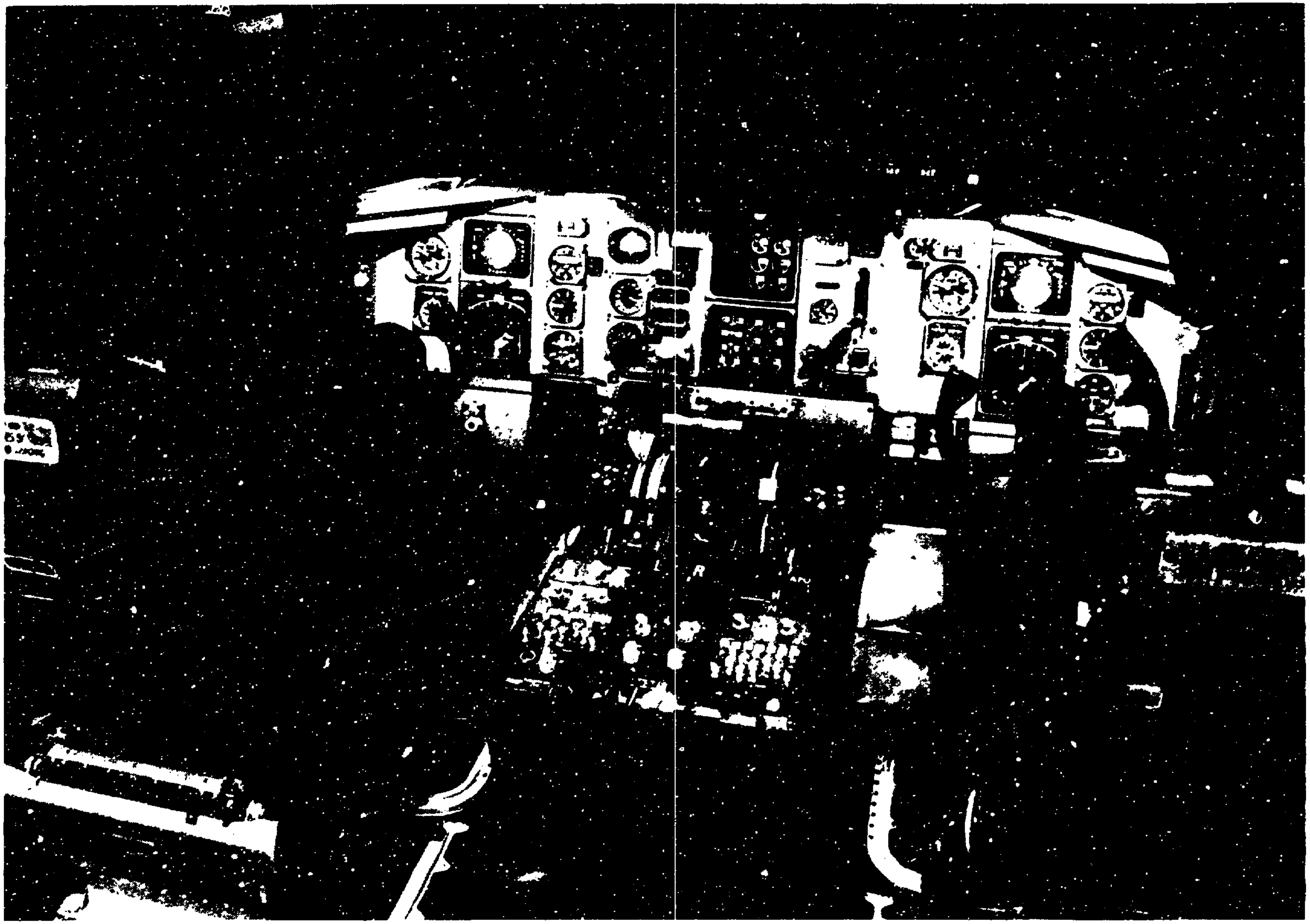


Figure 1. The Advanced Flight Deck of the Boeing Model 767 Aircraft

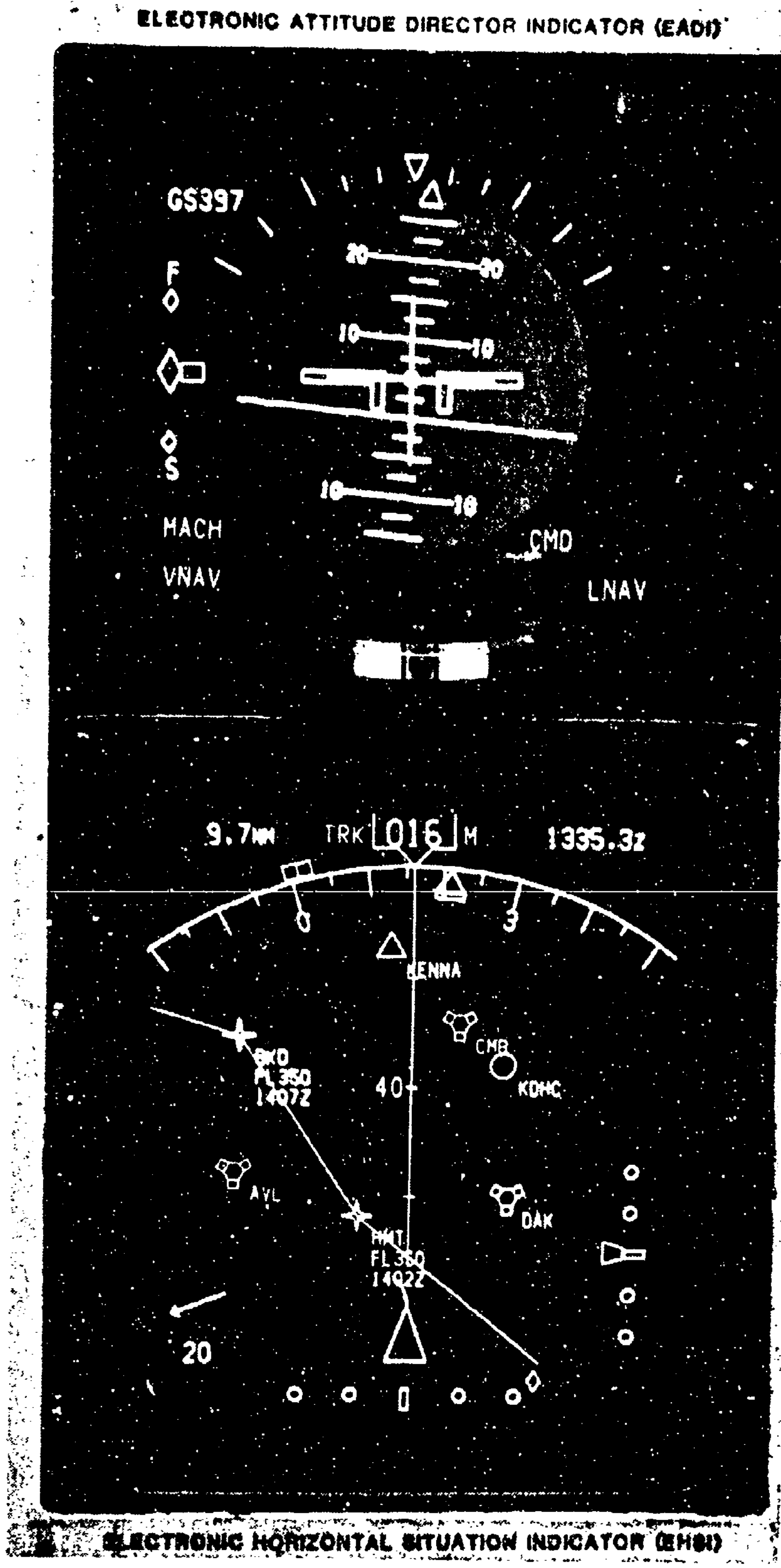


Figure 2. Boeing Model 757/767 EFIS System Displays Showing Typical Enroute EADI and EHSI Display Formats. EHSI Shown in Map Mode Without Weather Radar Imagery.

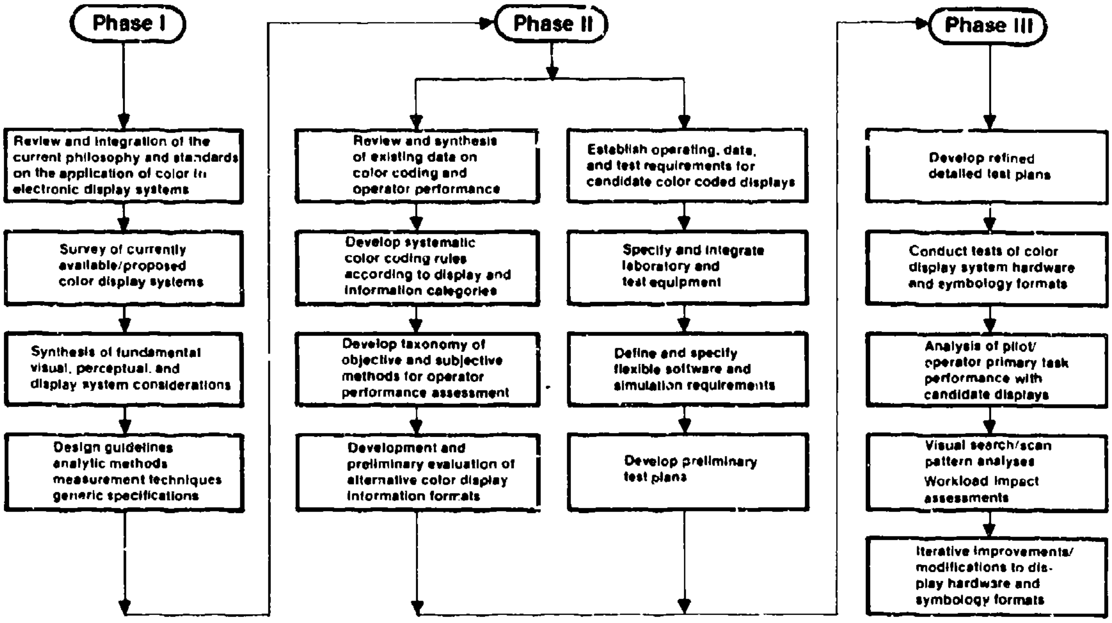


Figure 3. Current Program Plan for NATC Sponsored Color Display Development and Evaluation Activities

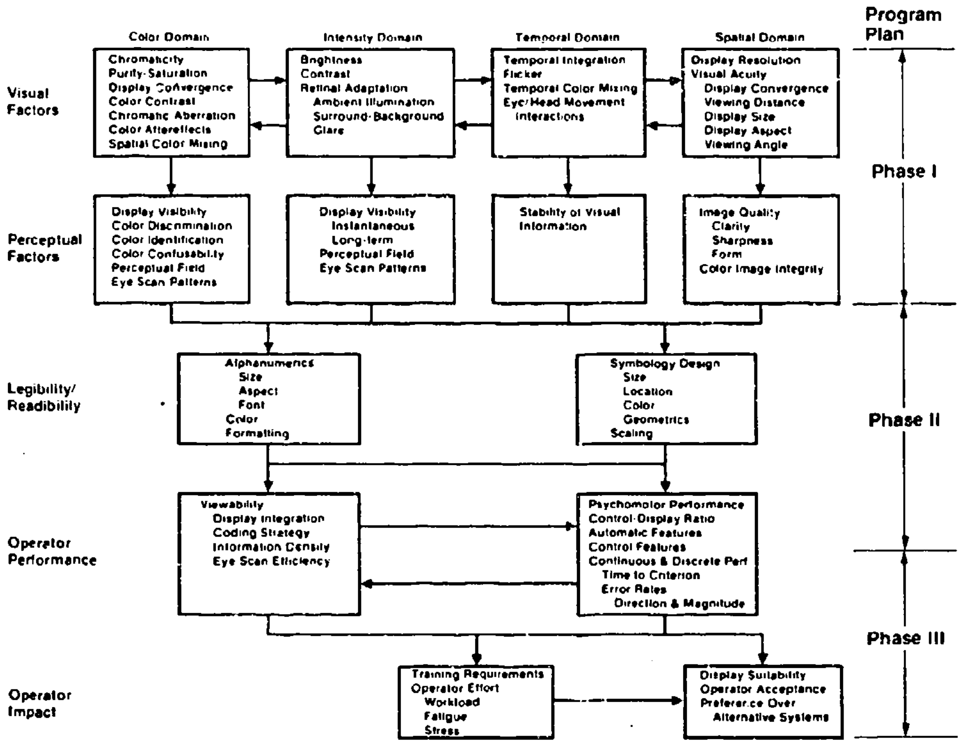


Figure 4. Hierarchical Human Factors Analysis for Color Display Systems (from Silverstein, in press) in Relation to Current Program Plan

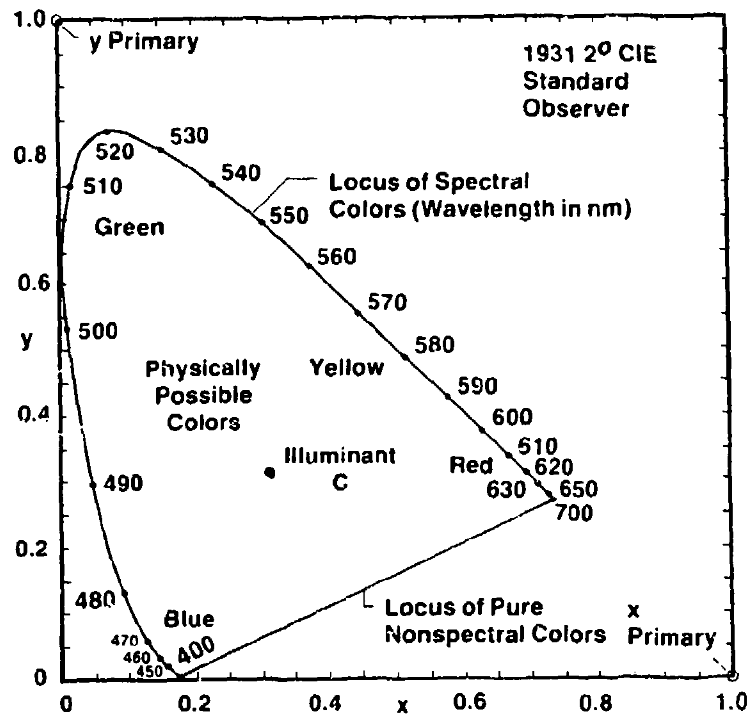
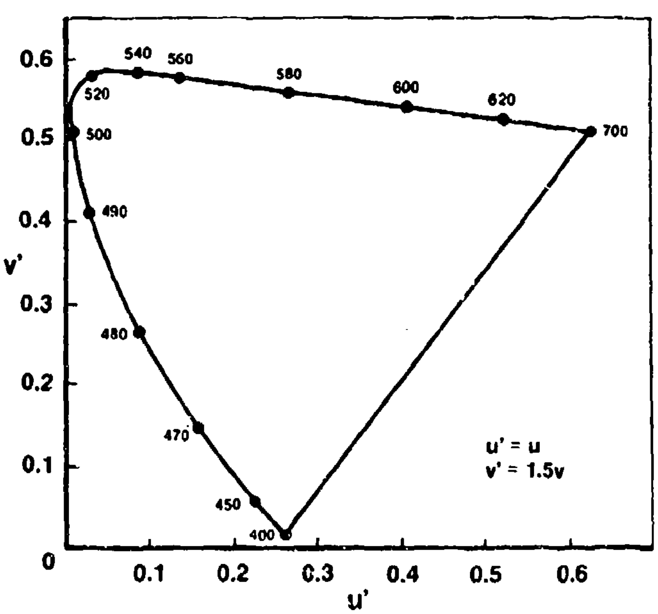


Figure 5. The Basic CIE (1931) Chromaticity Diagram



$$u' = \frac{4x}{-2x + 12y + 3} \qquad v' = \frac{9y}{-2x + 12y + 3}$$

Figure 6. CIE (1976) UCS Diagram and Associated Formulas for Conversion from the 1931 (x, y) System

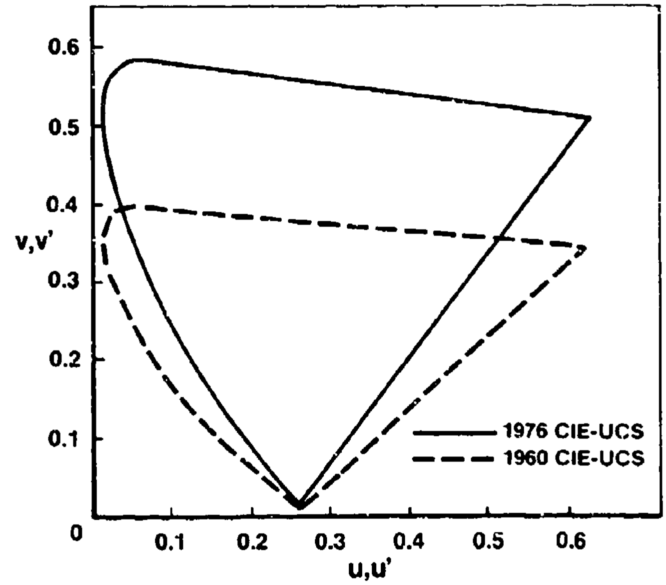


Figure 7. A Comparison of the CIE (1960) and CIE (1976) UCS Diagrams

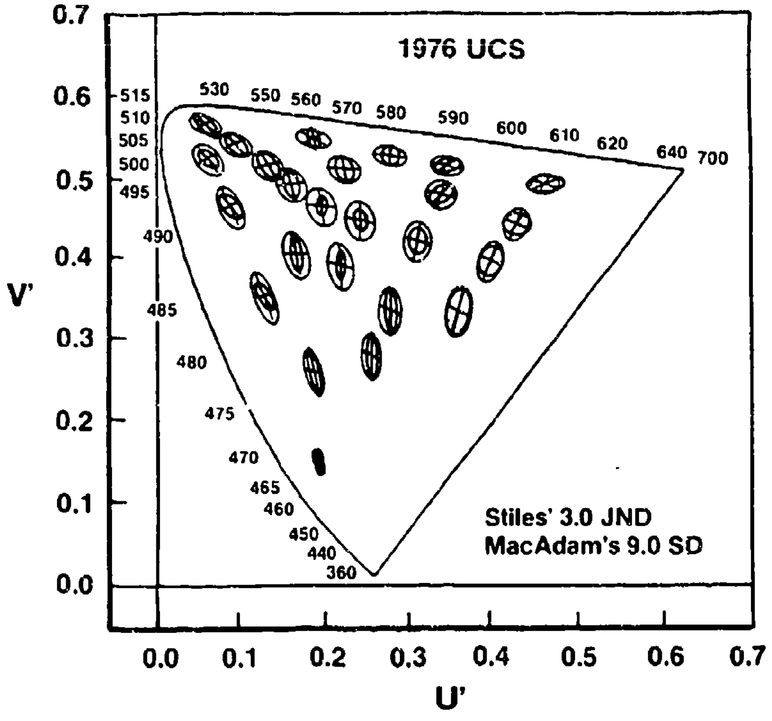


Figure 8. CIE (1976) UCS Diagram Showing Discrimination Ellipses Derived from Both MacAdam's Empirically Derived Color Matching Standard Deviations and Stiles' Line Element Predictions (adapted from Laycock & Viveash, 1982)

CIE (L*, u*, v*) Coordinates — Self-Luminous Display

$L^* = 116\,(Y/Y_N)^{1/3} - 16$ for $Y/Y_N > 0.01$

$u^* = 13L^*\,(u' - u'_N)$

$v^* = 13L^*\,(v' - v'_N)$

Y = Object color luminance

Y_N = Luminance for nominally white reference stimulus

u', v' = 1976 CIE-UCS coordinates for object color

u'_N, v'_N = 1976 CIE-UCS coordinates for nominally white reference stimulus

Typical nominally white reference stimulus is D_{65}

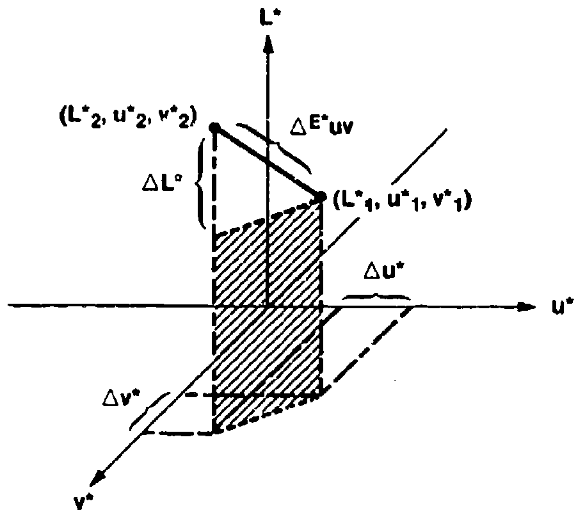
where y_N = Maximum possible image luminance

$u'_N = 0.1978$

$v'_N = 0.4684$

Figure 9. Derivation of CIE (L*, U*, V*) Coordinates

CIELUV Color Difference



$$\Delta E^*_{uv} = \left[(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2\right]^{1/2}$$

Figure 10. Three-dimensional Representation of CIELUV Color Difference Estimates (from Merrifield, in press)

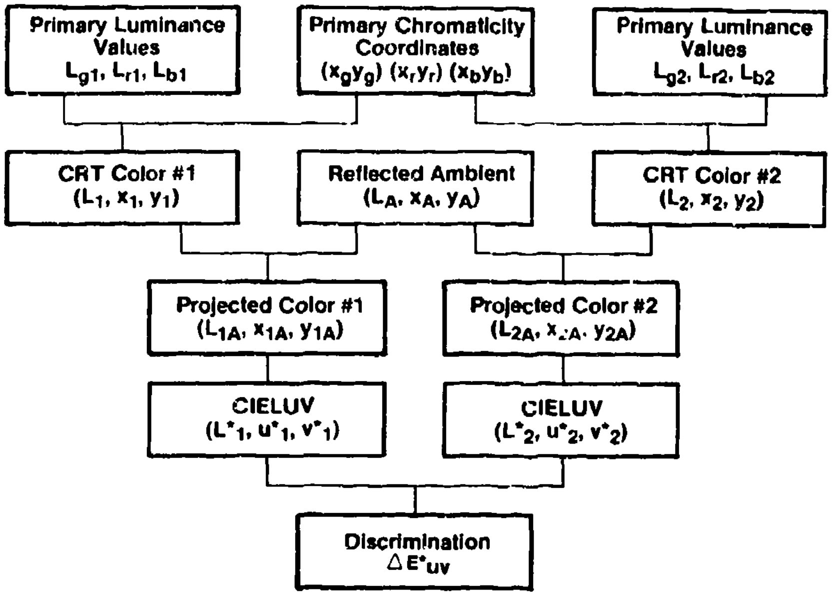


Figure 11. Application of CIELUV for Estimating Color Difference on an Electronic Color Display (from Merrifield, in press)

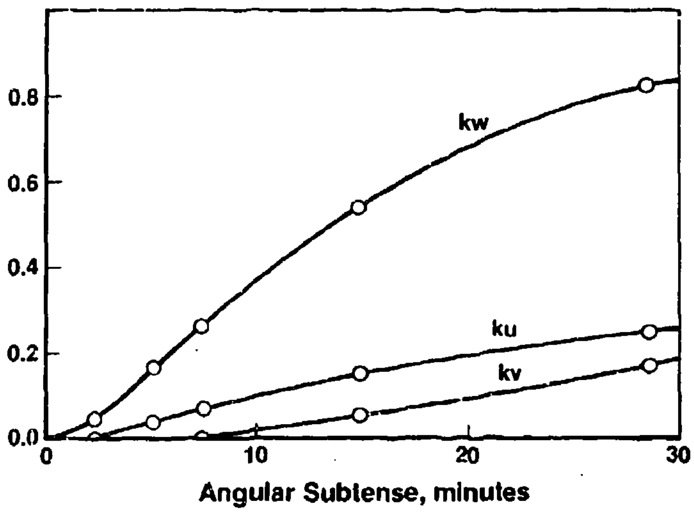


Figure 12. The Variation of Red-Green Factor, K_u, Violet-Green Yellow Factor, K_v, and Light-Dark Factor, K_w, with Angular Subtense of Small Colored Targets for the CIE 1964 (U^*, V^*, W^*) Color Space (from Judd & Yonemura, 1969)

Angular subtense, minutes of arc	Red-green factor	Violet-greenyellow factor	Light-dark factor
	k_u/	k_v/	k_L
32	0.270	0.133	0.850
16	0.160	0.043	0.575
8	0.072	0.003	0.285
4	0.020	0.000	0.105
2	0.003	0.000	0.032

The corrected CIELUV color-difference equation for small fields is then:

$$\Delta E^* = \left[(K_L \Delta L^*)^2 + (K_u{}' \Delta U^*)^2 + (K_v{}' \Delta V^*)^2\right]^{1/2}$$

Figure 13. Modified Small-Field Correction Factors (K_u', K_v', K_L) for the CIE 1976 (L*, U*, V*) Color Space

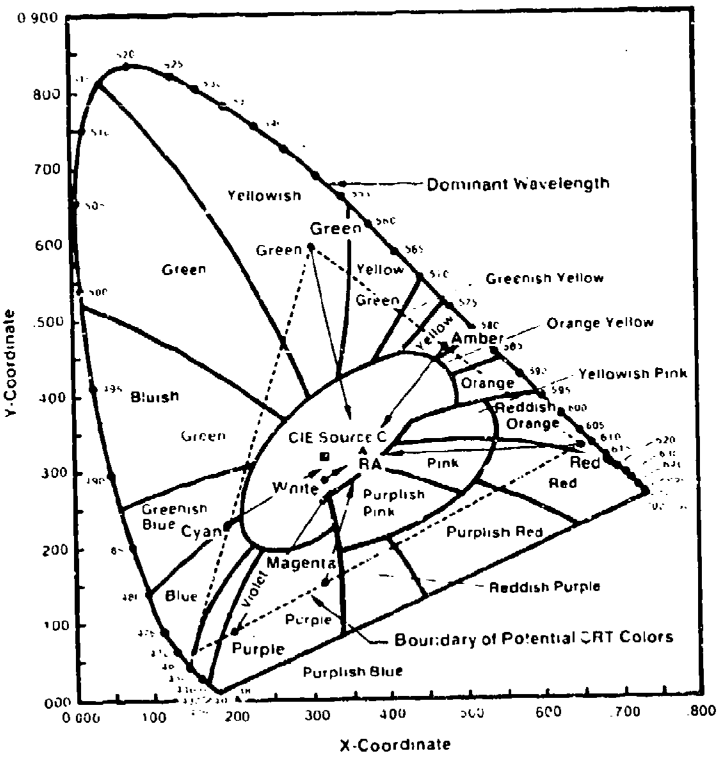


Figure 14. Shadow-Mask Display Colors Located in CIE 1931 Coordinates. The Point Marked RA Designates the Chromaticity Coordinates of Reflected Ambient Illumination. Directional Vectors Show Color Shifts due to 8000 ft-C of Ambient Illumination (after Silverstein & Merrifield, 1981)

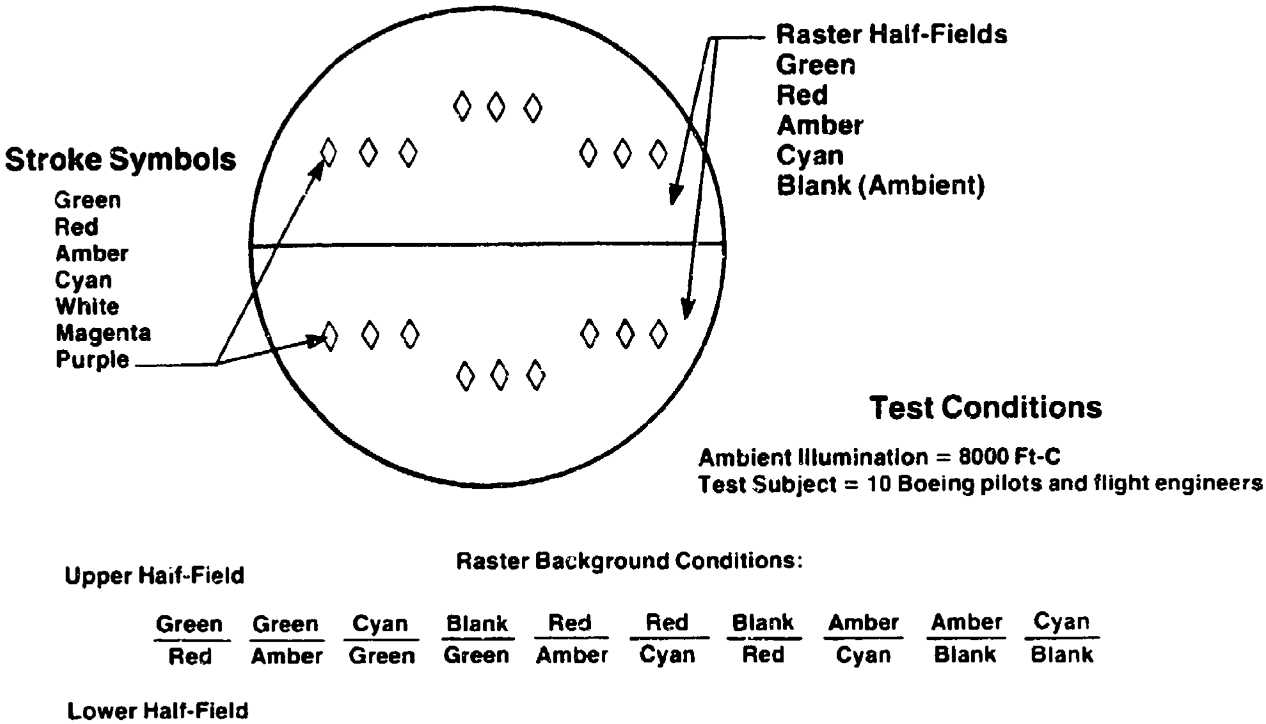


Figure 15. Color Test Pattern and Summary of Experimental Test Conditions for Visual Verification Testing of Shadow-Mask Color Display (after Silverstein & Merrifield, 1981)

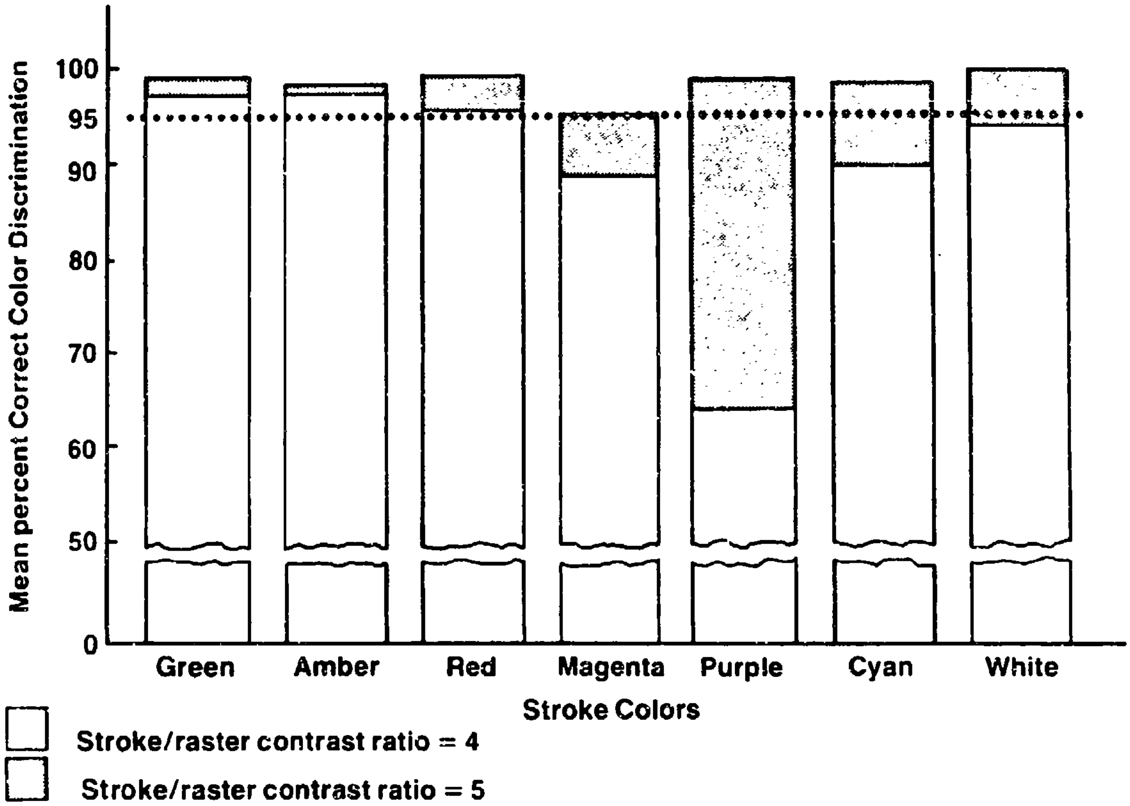


Figure 16. Stroke-Written Color Discrimination Performance (Averaged Across Color Raster and Reflected Ambient Backgrounds) as a Function of Stroke/Raster Contrast Ratio (adapted from Silverstein & Merrifield, 1981)

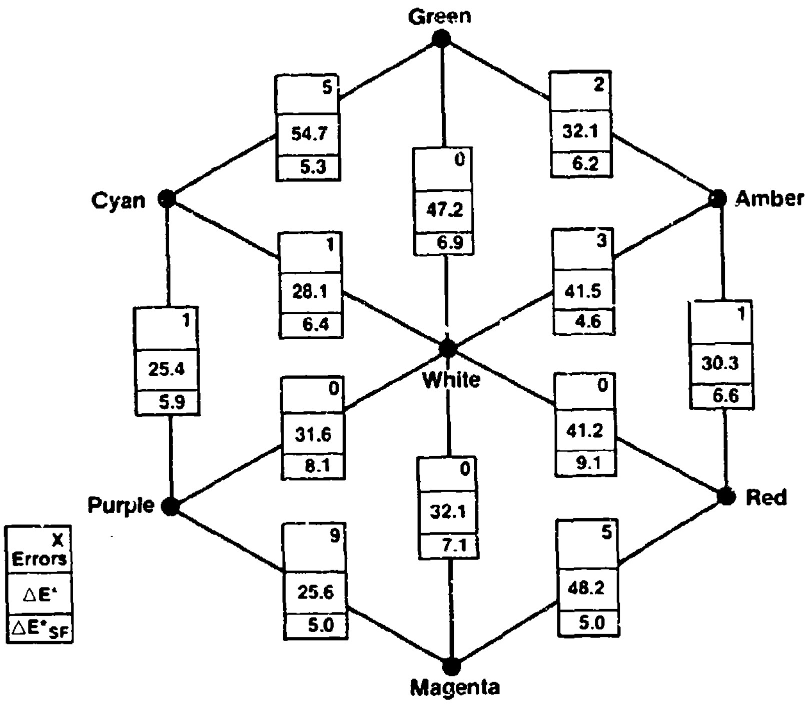


Figure 17. Color Confusion/Color Difference Matrix for Small Stroke-Written Symbols Viewed Under High-Ambient Illumination (from Silverstein & Merrifield, 1981). CIELUV Color Difference Computations are Shown for Both Uncorrected (ΔE^*) and Small-Field Corrected (ΔE^*_{SF}) Estimates

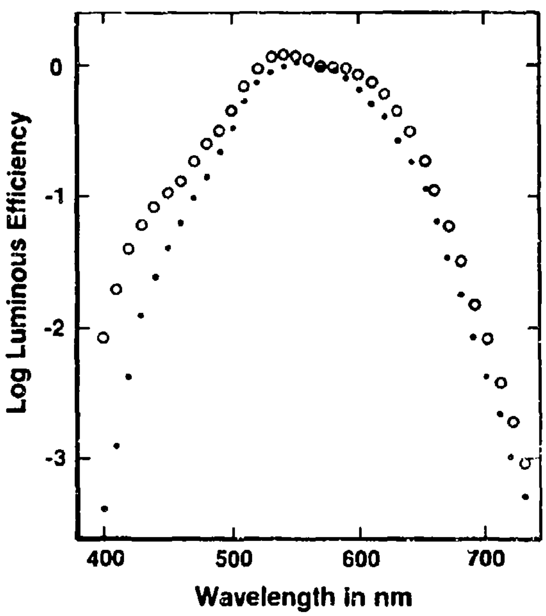


Figure 18. A Comparison of CIE V(λ) (•) and CIE TC-1.4's (o) Newest Assessment of Spectral Luminous Efficiency Obtained by Heterochromatic Brightness Matching (from Kinney, 1983)

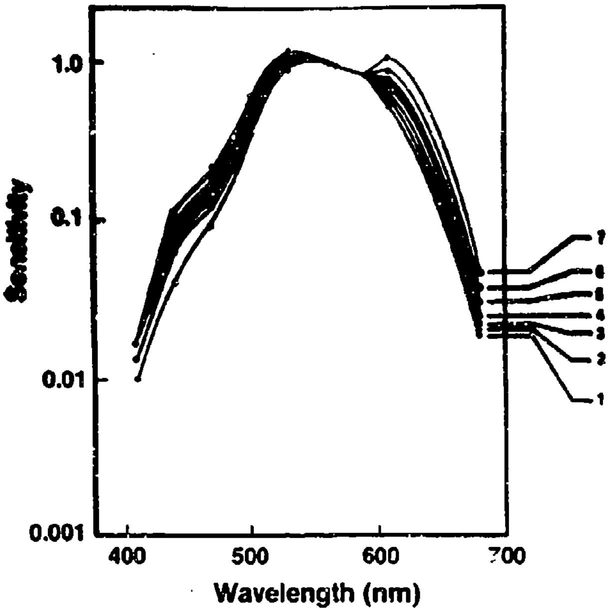


Figure 19. Spectral Luminous Efficiency as a Function of Purity. Purity = 1.0(7), 0.8(6), 0.6(5), 0.4(4), 0.2(3), 0.1(2), V(λ)-(1). (from Kinney, 1983)

λ	log V(λ)⁺	V(λ)⁺	N	V(λ)	B/L or V(λ)⁺/ V(λ)
400	-2.07	0.0085	8	0.000396	21.5
10	-1.71	0.0195	20	0.00120	16.2
20	-1.40	0.0398	33	0.00400	9.9
30	-1.22	0.0603	36	0.0116	5.2
40	-1.07	0.0851	36	0.0230	3.7
450	-0.98	0.1047	37	0.0380	2.8
60	-0.88	0.1318	37	0.0600	2.2
70	-0.73	0.1062	37	0.0910	2.0
80	-0.60	0.2512	37	0.129	1.9
90	-0.50	0.3162	37	0.208	1.5
500	-0.34	0.4571	37	0.323	1.4
10	-0.15	0.7079	37	0.503	1.4
20	-0.01	0.9772	37	0.710	1.4
30	0.06	1.1482	37	0.862	1.3
40	0.09	1.2303	37	0.954	1.3
550	0.09	1.2303	37	0.995	1.2
60	0.05	1.1220	37	0.995	1.1
70	0.00	1.0000	37	0.952	1.0
80	-0.01	0.9772	37	0.870	1.1
90	-0.02	0.9550	37	0.757	1.3
600	-0.06	0.8710	37	0.631	1.4
10	-0.13	0.7413	37	0.503	1.5
20	-0.22	0.6026	37	0.381	1.6
30	-0.35	0.4467	37	0.265	1.7
40	-0.51	0.3090	37	0.175	1.8
650	-0.73	0.1862	37	0.107	1.7
60	-0.97	0.1072	35	0.0610	1.8
70	-1.23	0.0589	35	0.0320	1.8
80	-1.50	0.0316	32	0.0170	1.9
90	-1.83	0.0148	21	0.00821	1.8
700	-2.08	0.0083	15	0.00410	2.0
10	-2.42	0.0038	6	0.00210	1.8
20	-2.72	0.0019	6	0.00105	1.8
30	-3.03	0.0009	6	0.00052	1.7

Figure 20. Tabled Values of Spectral Luminous Efficiency for CIE V(λ) and as Determined by Heterochromatic **Brightness Matching** $(V(\lambda)^{+})$. The Ratio V(λ)+/V(λ) Provides an Estimated **Brightness-to-Luminance** (B/L) Conversion for each Wavelength **Step (from** Kinney, 1983)

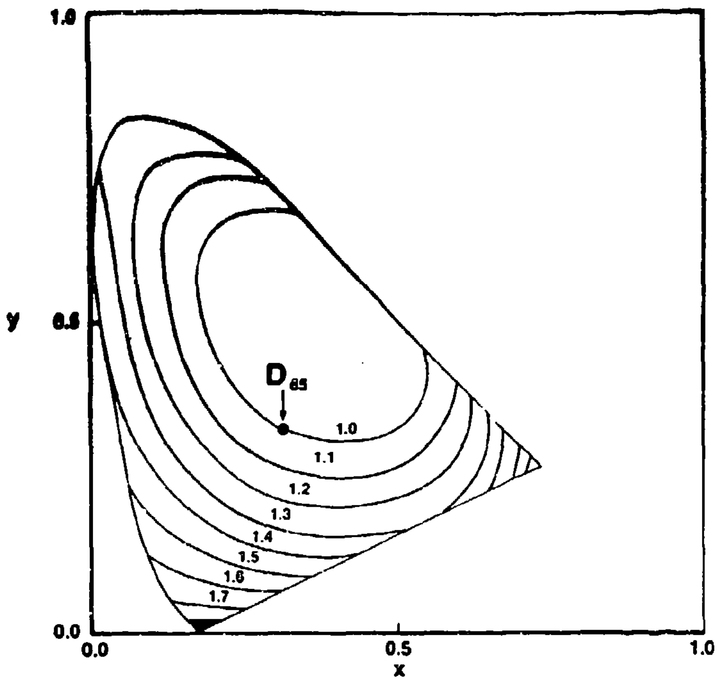


Figure 21. Equal Brightness-to-Luminance Contours for the CIE 1931 Chromaticity Diagram Calculated from the Luminance to Brightness Correction of Ware and Cowan (from Ware and Cowan, 1983)

Luminance to Brightness Correction (Ware and Cowan, 1983)

Correction Factor (C_s) = $0.256 - 0.184y_s - 2.527x_s y_s + 4.656x_s^3 y_s + 4.657x_s y_s^4$
where x,y = CIE 1931 chromaticity coordinates of color sample

Brightness Estimate - $\log(B_s) = \log(L_s) + C_s$
where L_s = Luminance of sample
C_s = Computed correction factor for sample

Figure 22. Correction Factor and Brightness Estimate Computations Derived by Ware and Cowan (1983)

Estimated Equal Brightness Values for Shadow-Mask Color CRT Primaries

Primary	Chromaticity Coordinates x	Chromaticity Coordinates y	Dominant Wavelength	C_s	log (B_s)	L (Ft-L)
Green	0.3000	0.5900	550nm	-0.0564	1.4207	30.0
Red	0.6530	0.3230	610nm	0.1154	1.4207	20.2
Blue	0.1500	0.0600	460nm	0.2232	1.4207	15.8

Figure 23. An Application of the Solution of Ware and Cowan (1983)

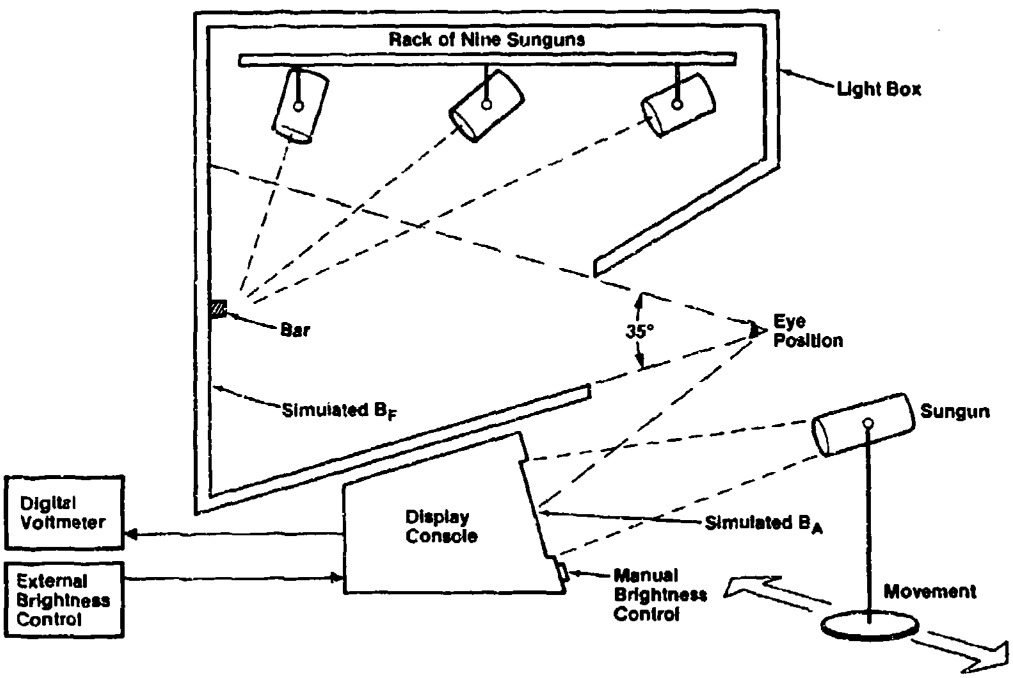


Figure 24. Ambient Light Simulator Used for Empirical Investigation of Automatic Brightness/Contrast Compensation System Control Functions

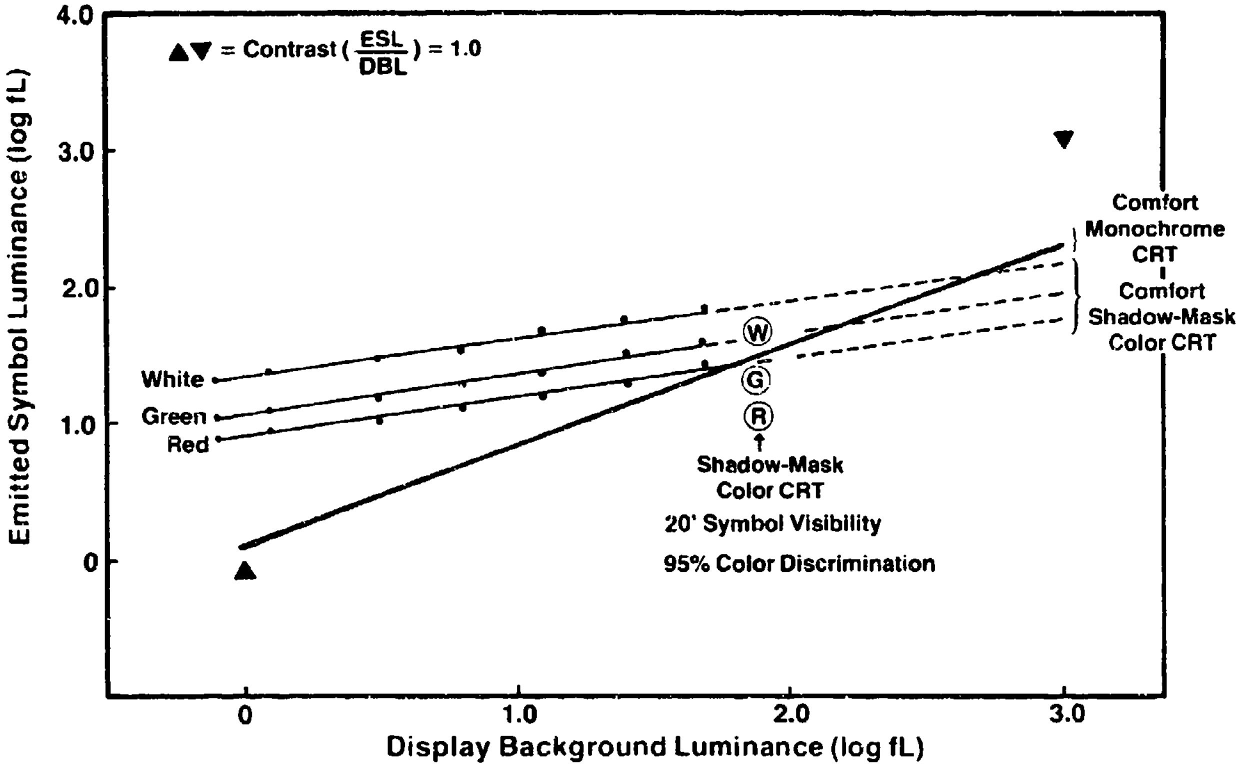


Figure 25. The Relationship Between Observer-Selected Emitted Symbol Luminance and Display Background Luminance for both Color and Monochromatic CRT Displays (from Silverstein, in press; Monochromatic Data Adapted from Knowles & Wulfeck (1972))

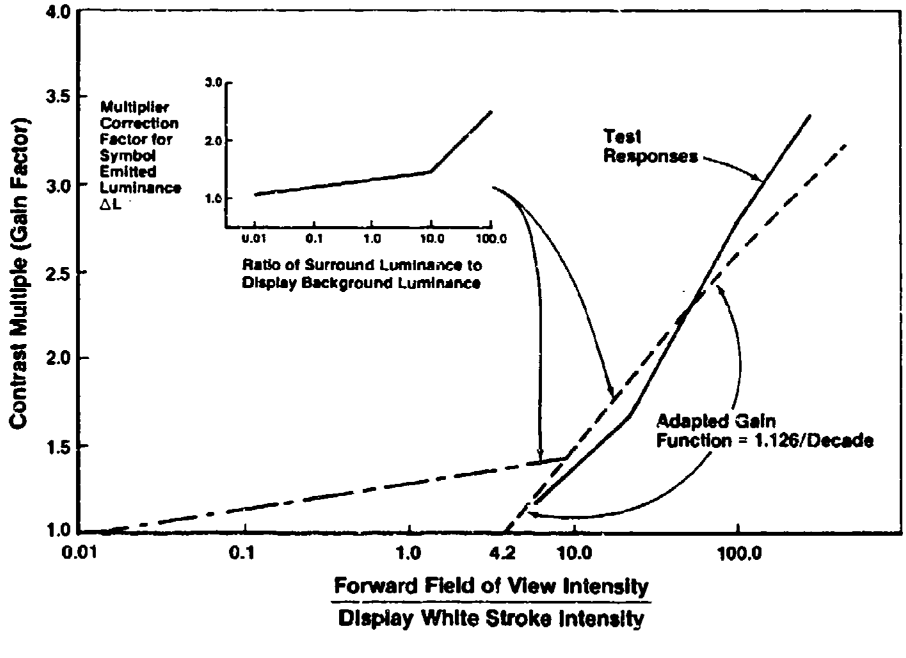


Figure 26. Derivation of Correction Factor for Eye Adaptation Mismatch-Transient Adaptation (Inset Adapted from Burnette, 1972)

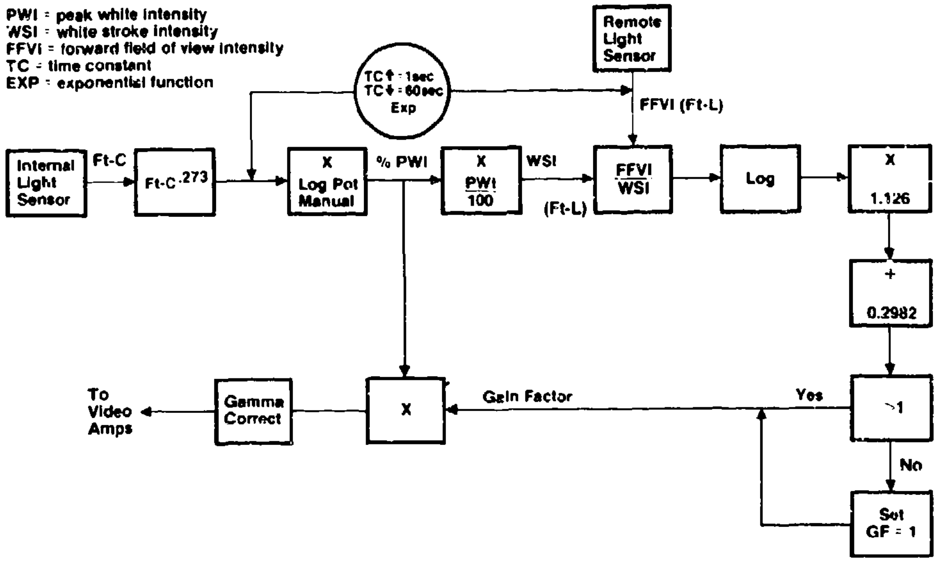


Figure 27. Functional Block Diagram of Automatic Display Brightness/ Contrast Compensation System for Dynamic Ambient Environments

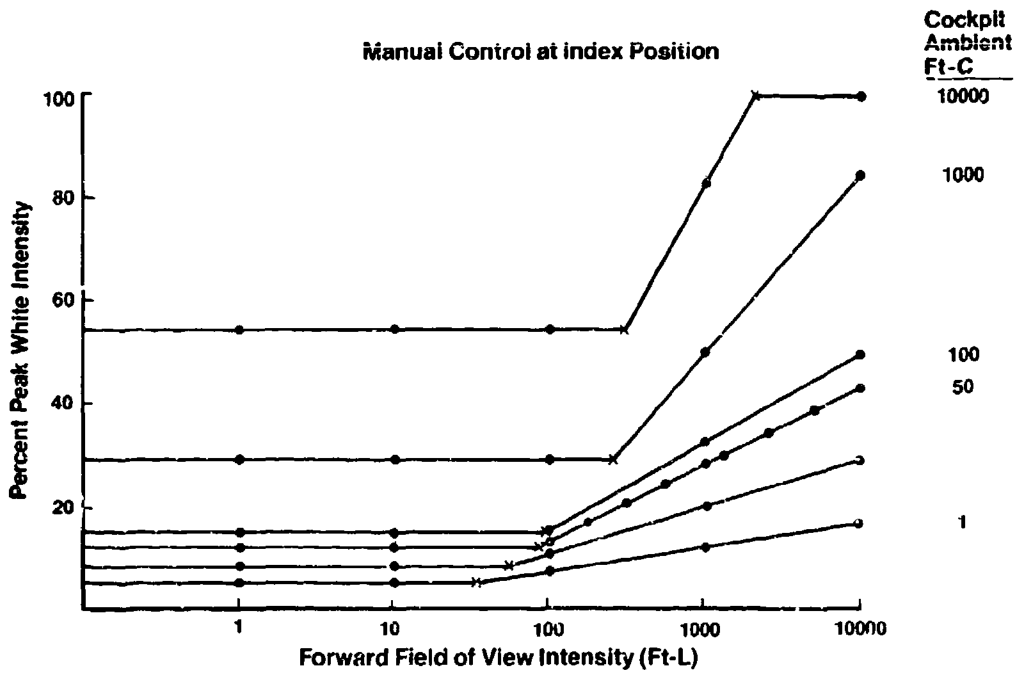


Figure 28. Automatic Brightness/Contrast Compensation System Response Characteristics

AIRBORNE ELECTRONIC COLOR DISPLAYS -

A REVIEW OF UK ACTIVITY SINCE 1981

by

J. Robert Caldow

Marketing Manager (USA), Electronic Display Systems

Smiths Industries Aerospace & Defence Systems Limited

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April 1984

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Introduction

Richard A. Chorley presented a paper at the 5th Aircrew Display Symposium in September 1981 entitled "Airborne Electronic Color Displays". During this presentation, Dick Chorley described the work which had been going on in the United Kingdom, under the aegis of the Department of Industry, and which, after many hours of simulator studies at the Weybridge facility of British Aerospace, had resulted in a color display system being installed in a BAC 1-11 research aircraft, of the Royal Aircraft Establishment at Bedford, to provide an airborne assessment of the potential of such a system in transport aircraft. The purpose of this paper is to outline the results of this airborne assessment and to indicate the extent of additional work which has been carried out in the UK over the last 2½ years.

Background

It is appropriate to describe briefly how the BAC 1-11 colour display system was configured and why.

Located side by side in the 1st Pilot's instrument panel were two large format shadow mask colour CRT display units conforming to ARINC Form Factor D. (Fig. 1) With an exterior cross-section of 8 inches x 8 inches, the Type D unit provides a usable display area of about 6½ inches x 6½ inches. There are no peripheral control buttons or

switches on the bezel, separate controls on the BAC 1-11 being mounted on the panel immediately above the displays. The side-by-side arrangement, with one unit more or less on the pilot's centre-line, was chosen to avoid obscuration by the control yoke which would have occurred if the units had been mounted one over the other.

Prior to the experimental work carried out in the Weybridge simulator, doubts had been expressed as to the acceptability of this side-by-side configuration but the majority of critics had not realised an essential feature of these two units. They were not, it should be stressed, an electronic ADI and an electronic HSI respectively. The unit in front of the pilot was a Primary Flight Display (PFD) and that inboard was a Navigation Display (ND). Experience in the aircraft confirmed that the side-by-side configuration was entirely acceptable.

The PFD provided all the information, presented in the same relative position, that is provided by the conventional T pattern of traditional electromechanical instruments. (Fig. 2)

The ND provided a traditional compass rose format if desired (Fig. 3) but, to maximise the flexibility of the CRT display in conjunction with the RNAV capability of the aircraft, the alternative format of the map (or chart) mode was provided. (Fig. 4) Whichever format was selected, additional navigational information was provided in the side frames - information such as GMT, distance- and time-to-go to next waypoint, true airspeed and so on.

Objectives

There were 3 objectives in the BAC 1-11 research exercise:

(a) To examine the problems of installing and interfacing this type of display in the environment of the civil flight deck.

(b) To demonstrate the use of color displays in their working environment.

(c) To make a direct comparison between the color displays and conventional electromechanical instruments - which were retained on the 2nd pilot's panel.

This paper will make no further reference to the first of these objectives.

Flight Experience With Color Displays

After an initial 60 or so flight hours spent on assessing the effectiveness of two monochrome displays, over 400 hours were flown with the full color versions. The views of more than 150 pilots who were able to see the color system working in flight - in the UK, Europe and the USA - contributed to the overall assessment.

General Color vs. Monochrome Impressions

Limited subjective impressions of the monochorme displays were favorable but recordings of pilot performance when flying manual ILS approaches revealed little difference between those flown with this type of display and those flown with conventional instruments. (There was no map format provided with the monochrome version of the ND.) (Fig. 5) Moreover, the uniformity of the monochrome presentation, combined with the small size of the analog scales on the PFD, was found to give a less effective indication of some flight information. A case in point was an occasional confusion between which was the ASI and which the altimeter - despite the fact that they were positioned in their conventional places in the basic T. The screen area on the monochrome displays was smaller (approximately 6½ inches x 5 inches) than that on the subsequent full color units and this limited the scale

sizes. Moreover, there was no heading scale on the monochrome PFD - a fact which had a direct influence on the initial criticism of the side-by-side installation in the early simulator experiments.

The addition of color (together with the provision of the larger CRT area in each unit) overcame the earlier criticisms of the monochrome displays, but most significantly provided more information in a more compact scan pattern than is possible using either monochrome CRT displays or conventional instruments. This is directly attributable to the improved symbol definition and discrimination which results from the use of color. The additional symbology on the PFD gives the pilot an improved monitoring capability and the selective presentation of relevant data prevents display clutter. The map mode on the ND used in conjunction with an area navigation system significantly reduces pilot workload since together they give:

(a) An instant pictorial presentation of the current situation.

(b) No requirement for manual selection of aids.

(c) No requirement for mental interpretation of navigational beacon ranges and bearings.

Scan

As already mentioned, the monochrome PFD had no heading scale and it had been difficult to bring the ND heading scale into the scan pattern. The scan distance to the heading scale was not great but was considerably further than that for other flight information on the PFD. This tends to confirm that a balance of distance is just as significant as total scan distance.

This aspect of scan did not generally arise with the larger Type D color displays, but the problem may be difficult to resolve on aircraft equipped with a number of smaller

CRT displays or those where the pilot scan has to include a combination of CRT displays and electromechanical instruments. Additionally, the type of eye stimulus from CRT displays and from conventional reflective instruments was found to be different with wide variations under changing light conditions.

The combination of these factors undoubtedly requires some pilot adaptation when a mix of CRT and conventional displays is provided and serious criticism was anticipated. This type of mixed instrumentation has of course now entered airline and general aviation service since the BAC 1-11 assessment and the absence of criticism indicates that there is no serious problem associated with the use of mixed displays.

Format

It is inevitable that pilots should have differing views on display formats. Many pilots expressed surprise that the BAC 1-11 displays were so conventional. It had never in fact been claimed that the display formats represented an optimized solution. The PFD format in particular had been adopted because it provided information in a manner essentially familiar to pilots trained on conventional instruments and permitted random pilot assessment of the concept of using CRTs for the display of primary flight data. It was in turn surprising to learn that so many of these "random pilots" were clearly familiar with some of the more advanced display concepts.

There was a consensus on the following features of CRT displays:

(a) The side-by-side arrangement of the PFD and ND was acceptable provided that all the primary flight information was on the one display.

(b) There was enthusiasm for the availability of such information as height warnings and optimum/safety/limit speeds whenever relevant.

(c) The map format was thought to be excellent. It is clear that the provision of a map display "astern" of the aircraft symbol has significant benefits for pilot orientation. Moreover, by enabling the pilot to study the intended route and the destination area, the "look ahead" facility was considered a substantial aid to he task of making changes to the programmed flight plan.

(d) Two adverse critisms were:

   (i) The presentation of analog radar height information when available (by superimposing it on the barometric altimeter scale).

   (ii) Heading-related information on the scales beneath the attitude indicator was cramped.

(e) Those pilots with experience of electromechanical strip scales considered that this type of presentation should be used on the PFD for the display of airspeed, altitude and vertical speed.

Color

The best colors were judged to be cyan, white and green, for they provided easily distinguishable sharp images. The most uncomfortable color was magenta, considered somewhat harsh. Other colors used in the BAC 1-11 displays were amber, blue, brown and red. (Fig. 6)

These eight colors were sufficient for the formats used on the aircraft. A total of 15 colors could have been made available by the system but, since the principal uses of color are the decluttering and coding of information, the use of more than 8 colors would probably have been counter-productive. Indeed, the use of fewer colors may offer advantages, given the appropriate format.

To allow for extended viewing periods, colors selected to display "normal" flight information must be balanced. This means that one color should not appear harsher and so more demanding of the pilot's attention than the others. The latter characteristic is of course an obvious requirement for the display of warning information.

The universally accepted color for warnings is red but a more striking color for this purpose is magenta. Warning indication could therefore more effectively be given using a red which is closer to magenta in the color spectrum.

All of this, of course, begs the question already asked by so many pilots; why has there been no standardization in the use of colors by the manufacturers? In fact working groups have been set up to make recommendations for commercial transport aircraft displays, including adoption of the current practice of using red, yellow and green for weather radar information. We should hope that these recommendations will assign preferred colors to the most used display functions. White, cyan and green are suggested as suitable colors and actual values, selected values and scales are considered to be the most used display functions.

Legibility

No difficulty was encountered in reading the displays, regardless of lighting conditions. Color saturation is reduced when direct sunlight is on the CRT but the colors have nevertheless been distinguishable even under the strongest sunlight experienced. Despite the fact that CRT brightness was considered perfectly acceptable for transport aircraft applications, the neutral density filters originally used on the BAC 1-11 displays are now being replaced by optical 'triple notch' filters to improve the contrast further.

The smallest characters used in the formats were 3 mm (0.118 in) high. Although no pilots found these characters illegible, a minimum height of 4 mm (0.157 in) was considered preferable.

Both the displays, PFD and ND, were legible from the opposite side of the BAC 1-11 cockpit with no parallax error. This feature will be a benefit in the truly "all-glass" cockpit, from the point of view of system integrity, but care will nevertheless need to be taken in cockpit display definition to avoid deep bazels or excessive tube curvature.

Flicker and Apparent Movement

The initial refresh rate selected for the displays was 50 Hz. At this rate, some flicker was perceptible and many pilots, seeing the displays for the first time, observed small apparent movements of the symbology - the so-called "jump" effect. This is due to the interaction between the moving fixation point of the eye and the refresh pattern of the display. Neither flicker nor jump degraded normal pilot performance and indeed these phenomena were not observed by pilots when concentrating their attention on the displays. Nevertheless, both effects are undesirable because they may tend to lower the pilot's confidence in the integrity of the displayed information. Moreover, flicker may reduce the impact of flashing warning symbols and indeed can degrade pilot performance if the frequency is as low as 15 Hz. Increasing the refresh rate to 60 Hz removed the flicker and reduced the jump effect and a rate of about 70 Hz effectively eliminates these effects.

Eye Fatigue

Eye fatigue was not a problem. On the contrary, the uniform lighting intensity of the displays at night was considered to be far more restful to the eye than the standard of lighting seen on the instrument panel of most current aircraft.

Summary of BAC 1-11 Assessment

The following summarizes the conclusions reached after the BAC 1-11 flight assessment:

(a) Color displays of this kind improve the interface between complex avionics and the flight crew.

(b) This integration was foreseen as becoming essential in the more demanding air traffic environment of the future.

(c) There was agreement among a large representative sample of pilot opinion, on fundamental issues:

  (i) The use of a single large format color CRT as a complete source of primary flight information.

  (ii) The side-by-side configuration of PFD and ND.

  (iii) The use of the map mode on the ND reduced the workload associated with the use of automatic navigation functions.

(d) Those pilots who had used both monochrome and color displays agreed that the use of color, enhancing as it did the presentation of information in general and of primary flight data in particular, had substantially reduced the workload of extracting information from the display.

(e) The use of color displays in the less benign environment of the military strike aircraft cockpit should provide adequate legibility under bright sunlight conditions.

Additional Research

Since the completion of flight assessment in the BAC 1-11, further research has continued in the UK in connection with various aspects of color display systems but, although

some software changes to the BAC 1-11 displays have taken place, no significant hardware changes have been made and the large format units continue to serve as a research aid in the airborne assessment of other avionic systems at RAE Bedford.

The civil flight deck simulator studies at Weybridge have now included a comparison between the BAC 1-11 side-by-side configuration of Form Factor D units and a one-over-the-other configuration of Form Factor C units. (Fig. 7)

The use of the smaller display units on the 2nd pilot's panel precluded the presentation of circular analog scales for airspeed, height and vertical speed and these were replaced by vertical strip displays on the Form Factor D displays as well. (Fig. 8) The attitude display became a truncated circle, with a larger radius on the Form Factor D than on the BAC 1-11. On the Form Factor C displays, the presentation of heading was limited to the lower HSI display. Other noteworthy symbology changes included:

(a) The provision of (cyan) "boxes", for selected values of airspeed and height, which are superimposed on the respective strip scales.

(b) "Rolling counter" numerical readouts of actual values of speed and height.

Military Studies

Further research work on color displays for airborne military applications includes:

(a) Simplification of system hardware.

(b) Provision of symbol generation within the display unit.

(c) Environmental hardware studies vis-a-vis color displays in the helicopter cockpit.

(d) Compatibility studies of color displays and night vision goggles.

(e) Provision of primary flight information on smaller display units.

(f) Pseudo 3D displays.

Several of these areas merit a separate dissertation of their own but, in the context of this paper, which has been heavily slanted at the human factors aspects of color displays, further mention is probably appropriate only in respect of the last two, especially as far as the military single-seat strike aircraft cockpit is concerned. It is in this environment, possibly more than any other, that pilot workload reduction opportunities can never be ignored.

Multi-Purpose Displays

Dimensional limitations of the strike aircraft cockpit has led to the general adoption of the Multi-Purpose Displays (MPD) and current development in shadow mask CRTs will provide full color displays of adequate ruggedness, brightness and resolution for most purposes. In particular, a reduced screen phosphor dot triad pitch of 0.2 mm will offer a usable beam width of around 0.3 mm which is compatible with video sensor displays (although the full resolution of an 875 line sensor could not be exploited on smaller displays).

Ruggedised shadow mask technology will therefore provide for a flexible mixture of stroke and raster/video formats as appropriate to a military multi-purpose display.

Pseudo 3D Displays

The introduction of perspective topographical displays in lieu of a conventional moving map presentation may be the appropriate point at which to incorporate the well-publicized

"highway-in-the-sky" flight guidance techniques. It is probable that the use of color would significantly enhance a combined display of this type. Indeed, it is likely that only by the use of color could such a combination become generally acceptable.

Conclusion

In this age of the video game parlor, there is a growing body of pilot opinion which contends that addiction to traditional airborne display techniques is at best a failure to optimize the flexible characteristics of the color CRT and at worst an insult to their data assimilation capability.

Reference

1. N.W. Witt and E. Strongman "Application and experience of color CRT flight deck displays" - Displays, April 1983.

Acknowledgement

Much of the work described in this paper has been carried out by the Royal Aircraft Establishment at Bedford, England with the support of the United Kingdom Department of Industry and Ministry of Defence.

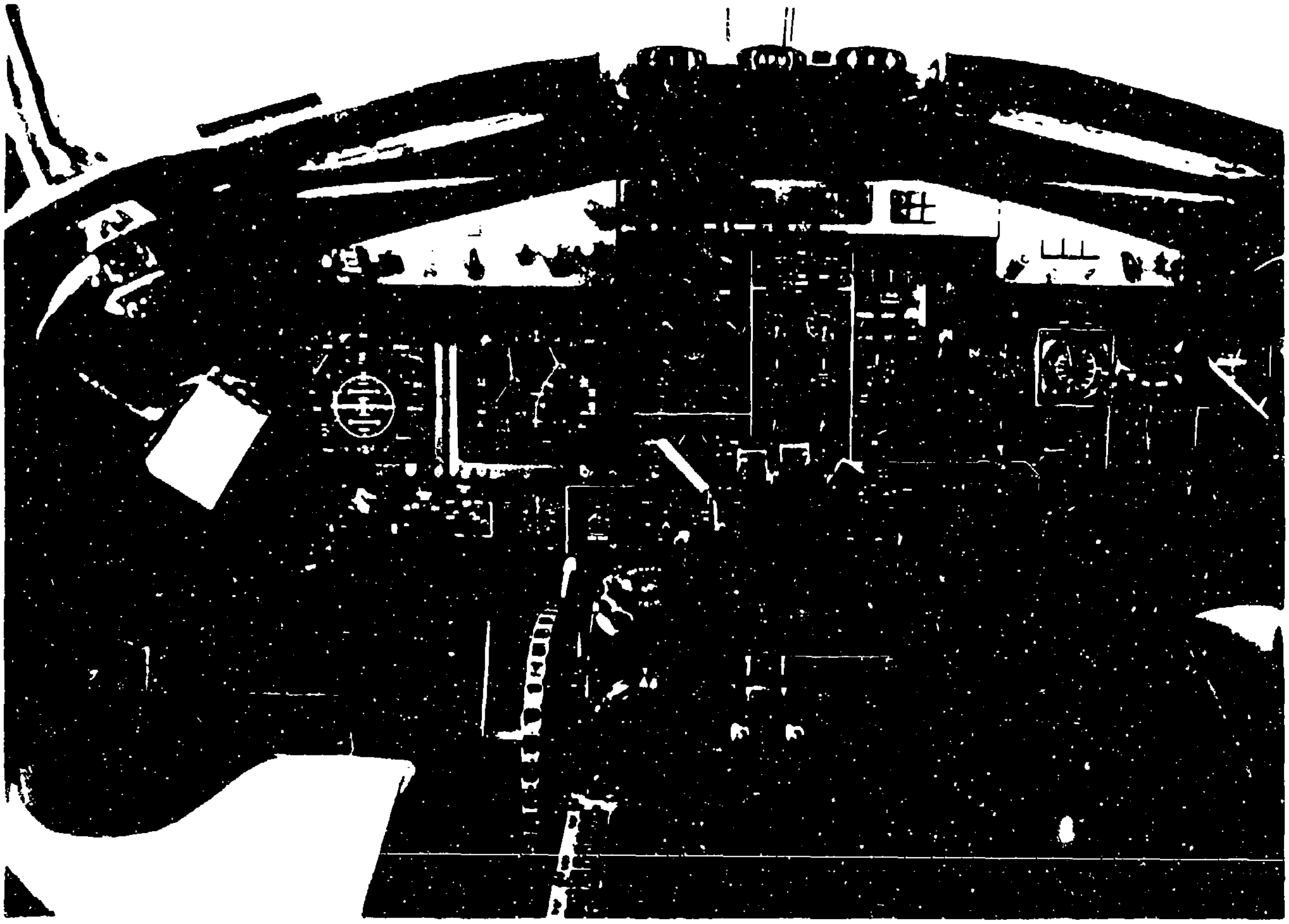

FIGURE 1

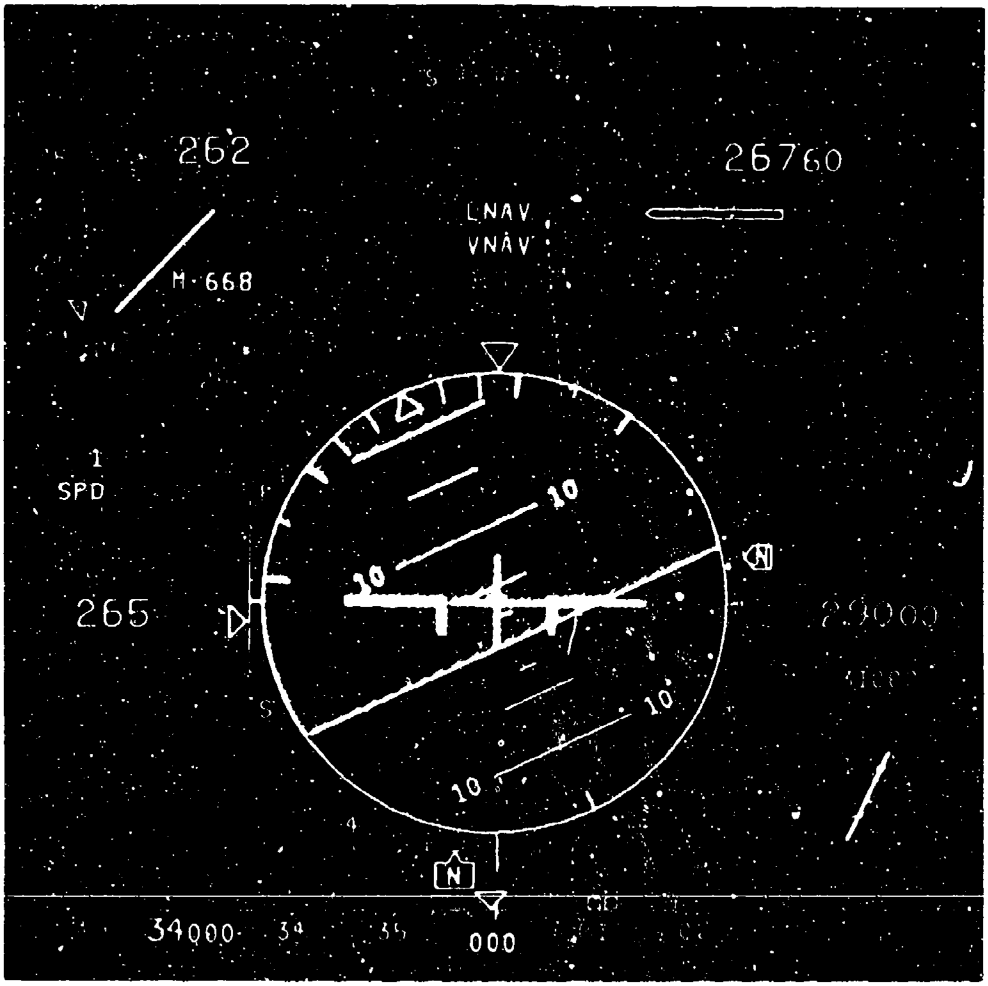

FIGURE 2

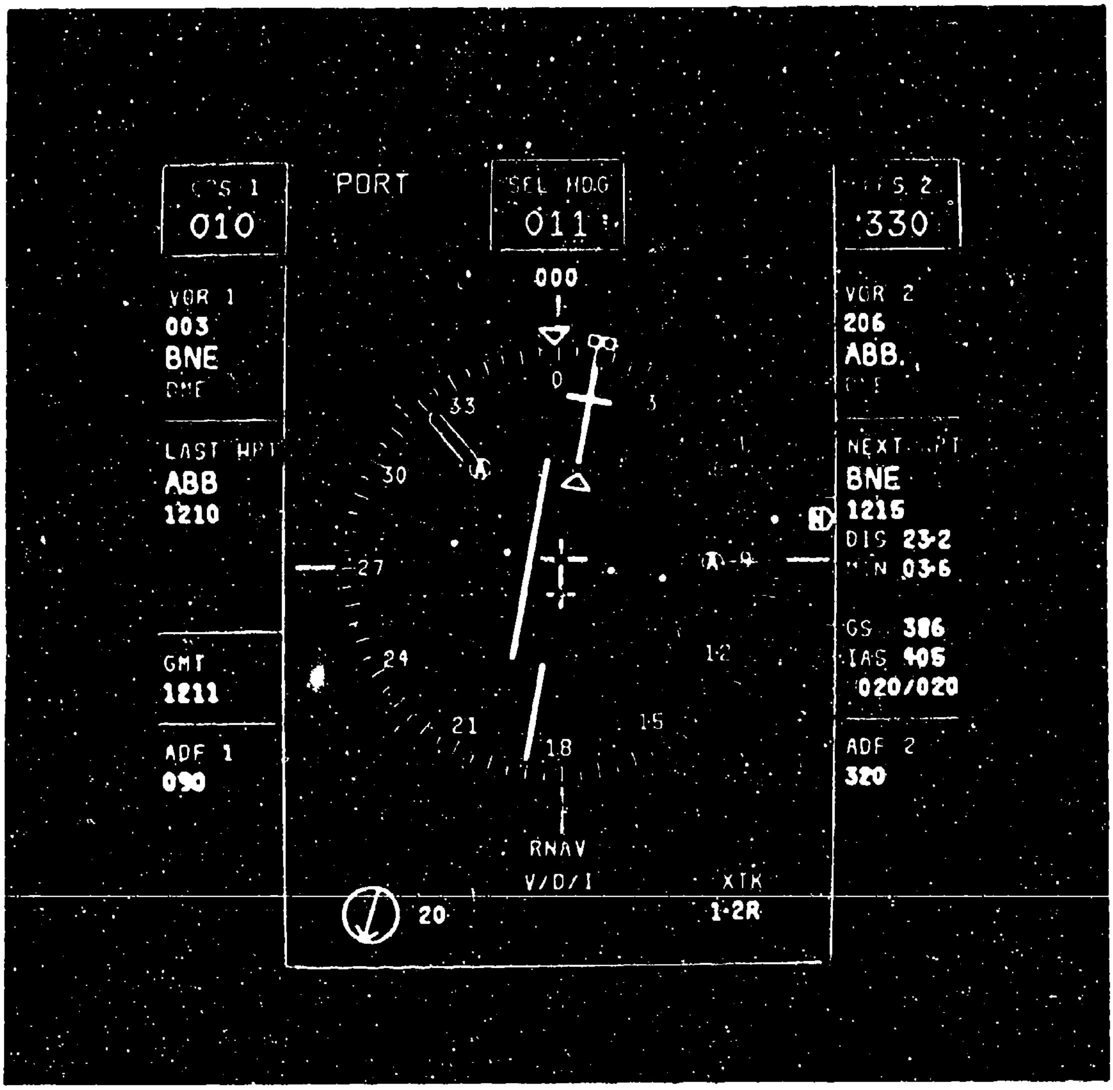

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FIGURE 3

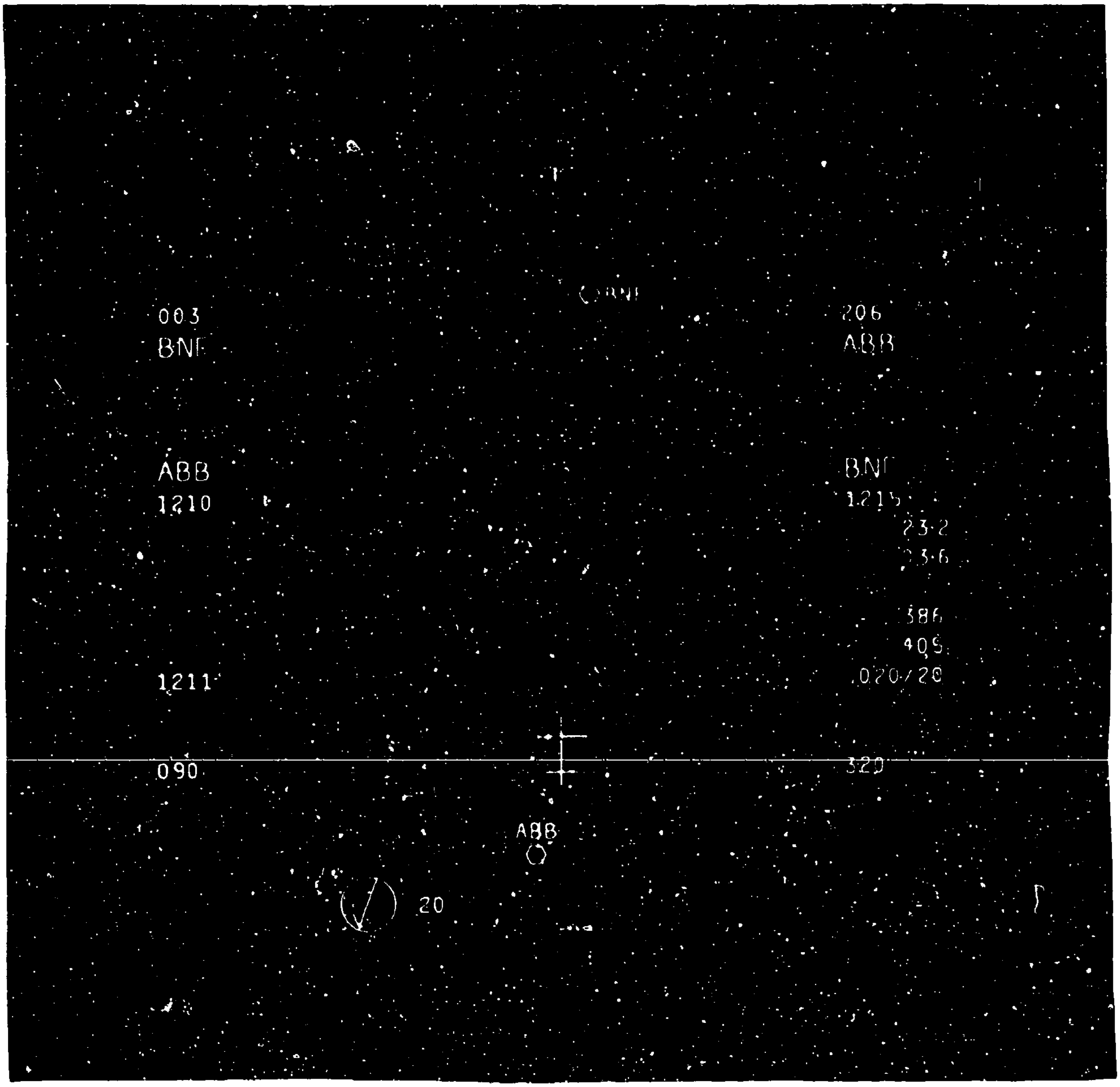
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FIGURE 4

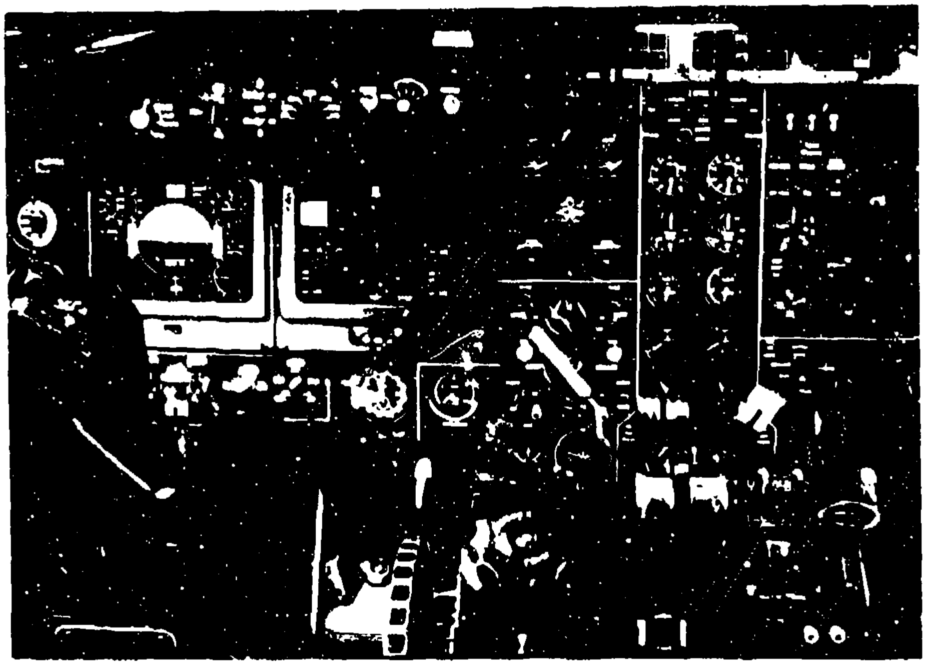

FIGURE 5

BAC 1-11 CIE CO-ORDINATES

Colors used in the BAC 1-11 displays had the following CIE co-ordinates:

	X	Y
Red	0.659	0.322
Green	0.290	0.588
Blue	0.178	0.166
Cyan	0.197	0.235
Yellow	0.497	0.439
Magenta	0.282	0.172
White	0.333	0.333
* Sky Shading (Blue)	0.186	0.191
* Ground Shading (Brown)	0.556	0.396

* (These colors were written at lower intensity.)

FIGURE 6

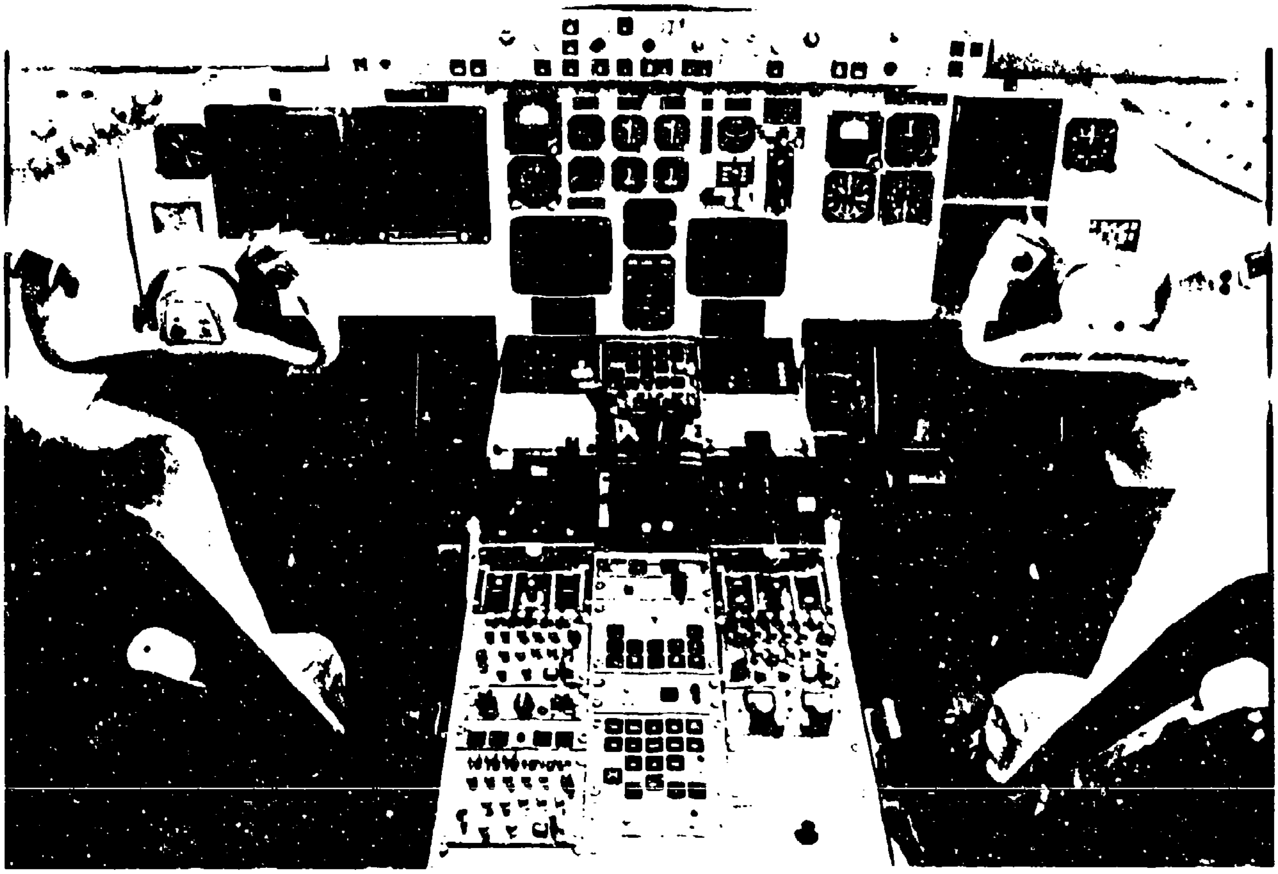

FIGURE 7

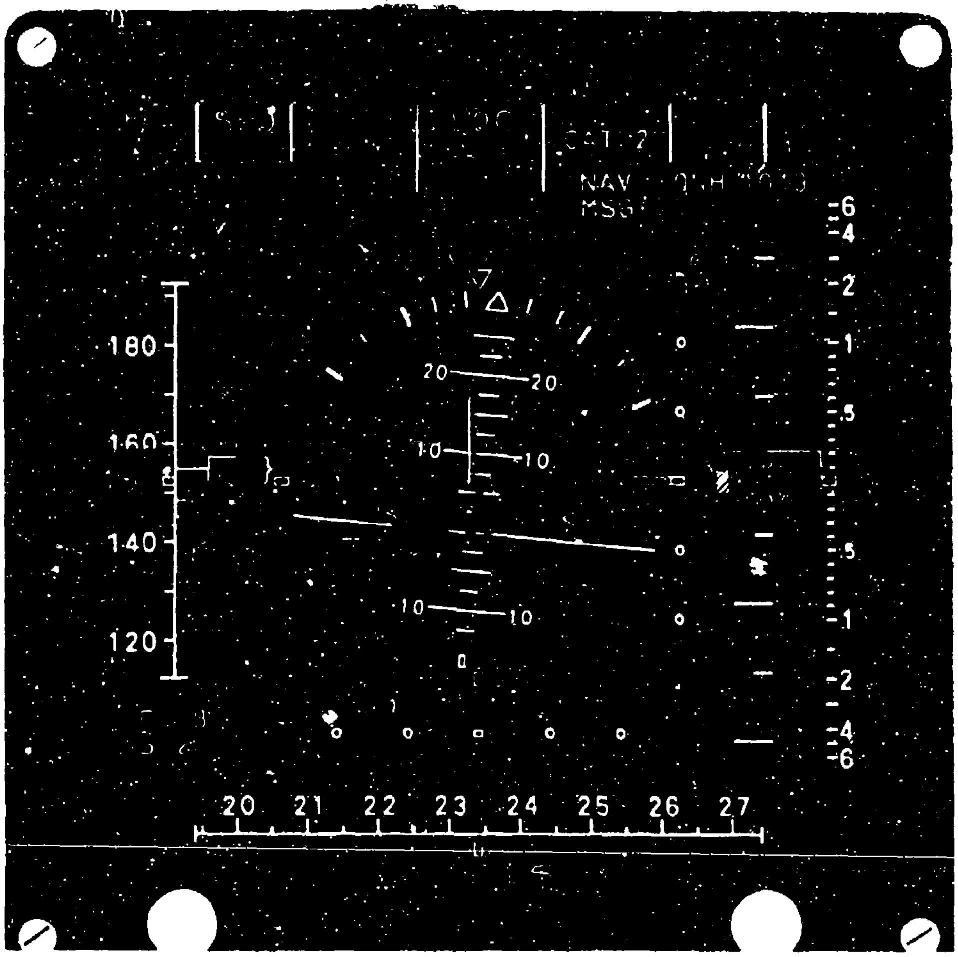

FIGURE 8

COLOR CRT IN THE F-15

by

John Turner and Harry Waruszewski
Sperry Flight Systems
Albuquerque, New Mexico

Abstract

The successful incorporation of a multi color shadow mask CRTs in commercial air transport flight decks paved the way for a broad range of potential application of shadow mask technology in the military avionics environment. The initial application of multi color shadow mask technology in a tactical aircraft is being applied in the F-15 aircraft under contract with MCAIR.

A very high resolution multi color shadow mask cathode ray tube display, designed specifically for military avionics, is described. The F-15 display accommodates either a very high resolution CRT developed for this application in conjunction with Tektronix, Inc., or a conventional high resolution shadow mask CRT from a Japanese supplier.

An overview of the F-15 system is provided including functional modes and capabilities. Typical operational display formats are shown, including multi color stroke-generated maps. A discussion of multi color shadow mask CRT's is provided in terms of resolution, brightness, color and color purity. Color filtering and contrast enhancement are discussed. Additional multi color shadow mask development are discussed such as the new very high resolution 6" X 6" CRT and the new Commercial ARINC "D size".

Introduction

The U.S. Air Force conducted studies into the use of Color Displays in the cockpit and their capability of meeting the military environment. The first study in 1978 for Warner Robbins AFB involved placing a color weather radar display in the C-141 aircraft. The results of some testing and data indicated that the displays would not meet the military requirements to the full extent. Warner Robbins proceeded with the color weather radar system and it has been well accepted. The user has requested an expanded role for the displays (i.e., symbology for data presentation in addition to just radar).

The second study was requested by the F-15 System Program Office (SPO) to investigate the feasibility of using a color display in a bubble canopy fighter cockpit environment. The need for color had to be established. A report of the studies conducted by D.J. Oda of Lockheed Co. on ASW Aircraft such as S-3A indicated that color displays reduced the average ASW display analysis time from 9.16 seconds for a monochrome display to 3.16 seconds for color.[1] Studies were conducted by the Air Force Flight Dynamics Laboratory for the early Joint/Tactical Information Distributor System (JTIDS) effort to determine if color coded symbols in a highly dense situation display could improve pilot performance and reduce workload. The findings indicated that color coded symbology provided a significant reduction in the error rate and detection

time.[2] McDonnell Douglas, as part of the JTIDS/F-15 effort, conducted simulation tests of a monochrome display versus a color display. The MCAIR findings indicated a color display was a necessity once a high density JTIDS-tactical display was presented. The unanimous opinion of the users was that the JTIDS display must provide color in the single seat cockpit to be useable.[3] The Air Force Human Factors Engineering group ASD/ENECH conducted single seat air to ground evaluation of a color display versus a monochrome display. Their unpublished findings indicate that a color tactical display had a definite advantage in single seat operations. Discussions with A-10 French and British test pilots all indicate that a color moving map display is extremely more useful than a monochrome display. Additional flight tests will be forthcoming on color displays.

During the second study, contrast and brightness tests were made on a color beam penetration CRT in a military point source ambient environment. The beam penetration display did not have enough brightness to be totally useable. The color beam penetration CRT display was modified with a directional filter and testing reconducted, this time successfully passing the test. The F-15 SPO was notified that a suitable color display could be designed to meet the bubble canopy environment. The color beam penetration CRT would provide three colors, red, yellow and green, for threats, unknown and friendly, in a tactical presentation.

During the development of the beam penetration CRT display criteria, Boeing Aircraft Company announced their selection of a color shadow mask CRT display for the 757/767 aircraft. Not too long after that the European Airbus also announced it would use a shadow mask color CRT. The F-15 SPO requested Air Force engineering to evaluate the possibility of using the color shadow mask CRT in the F-15 aircraft in lieu of the beam penetration CRT. A third study was conducted in 1980. Shadow mask color CRT's were tested for brightness levels in the stroke mode. The shadow mask stroke mode displays were also visually tested for suitability of color difference identification in the high ambient illumination. The results of the readability tests of a shadow mask CRT in high ambient were very satisfactory, however, reservations were pointed out to the F-15 SPO about the vibration problems that may be encountered due to the high level of vibration in a military fighter compared to a commercial aircraft. Demonstration tests were set up for Air Force witnessing to demonstrate a ruggedized shadow mask CRT design for withstanding the vibration levels. The tests indicated that a color shadow mask CRT could indeed be used in a military vibration and ambient light environment. The F-15 SPO was notified that either color display technology could be used to meet the JTIDS display requirements, however, the color shadow mask CRT provided the most flexibility for growth into other display applications such as moving map display, caution and warning, flight instruments, etc.

F-15 Color Display

Sperry Flight Systems was awarded the contract by McAir for the F-15 Color display system for the JTIDS/PACS (Programmable Armament Control System) display. Because of the unique shape of the JTIDS/PACS display, Sperry developed an additional display in a more standard configuration utilizing the same subassemblies was developed for other application such as the Dual Role

Fighter (DRF). The JTIDS/PACS display is a color display that was designed for forward and retrofit applications into all existing F-15s. The F-15E (DRF) will utilize three of the square standard configuration 5-inch color displays.

The Multipurpose Color Display (MPCD) is a high resolution 5-inch by 5-inch shadow mask display unit capable of displaying stroke, raster or hybrid (stroke and raster) formats in full color and is driven by the Programmable Signal Data Processor. The stroke symbology can be displayed in any of 16 different colors, with each of the color coordinates programmable by symbol generator software. In the raster mode the red, green, and blue outputs of a color sensor or subsystem are processed to display full color analog raster such as the remote map reader planned for the F-15E.

Programmable Signal Data Processor (PSDP)

A programmable signal data processor designed by Sperry drives the MPCD. As shown in figure 3, the PSDP interfaces with aircraft avionics and sensors, and processes the data to generate independent formats on two monochrome displays, one color display, and a repeater. The PSDP contains two separate processing systems in one package -- a triple-channel symbol generator and a general purpose processor. The symbol generator portion processes avionics digital and sensor information to drive the four displays. The general purpose processor can be used for a variety of applications. In the F-15 it processes JTIDS information and passes the resultant display formats to the symbol generator processor via a shared memory. The PSDP also acts as the 1553 Bus Controller for the JTIDS System and as the aircraft overload "G" warning computer.

The symbol generator processor software contains a macro interpreter that provides flexibility in generating formats from external (central computer and radar) and internal (GP processor) sources. Essentially, the display macro approach establishes a data base in the PSDP RAM that is fully controllable by a driver in the central computer or GP processor. This driver can change the commands and data sets within a macro program at any time in order to add, remove, change or move symbols on the display screen. The macro interpreter converts the data base to object code, which is directly executable by the symbol generation channels. This type of configuration yields optimum capability and flexibility yet is conservative in the use of the PSDP and central computer memory space.

The PSDP-MPCD interface is shown in figure 4. The multiplex interface (data, clock, and initiate) is a unidirectional serial bus that routes switch and BIT data from the MPCD to the PSDP. Data transfer is controlled by a special I/O instruction in the symbol generator processor. Deflection signals contain combined stroke and raster information since the sweep generators are located in the PSDP. Horizontal sync is used in the raster portion of the hybrid mode to flyback the X beam to the left edge of the screen. Vertical blank and raster/stroke signals are used to switch between stroke and raster modes. The end of slew signal enables writing stroke symbology once the beam is settled after a new command position. BIT initiate commands the display to the initiated BIT mode. Brightness and contrast functions are processed in the PSDP in response to rocker switch depressions processed by the PSDP to generate the focus-control signal, which maintains sharp focus at all brightness levels. The red, blue, and green drive signals contain combined stroke and raster video.

Color Display Details

A 5 X 5-inch high-resolution, delta gun shadow-mask CRT is used in the MPCD. Dynamic and static convergence are provided to obtain maximum symbol fidelity. High ambient viewability is achieved by using a 25 kV anode voltage, in concert with a bandpass filter on the CRT and 17K inches-per-second stroke writing speed. Two CRT versions are being developed that will be interchangeable at the CRT and yoke assembly level. The Matshusita CRT has a spacing of 0.012 inch between color triads and the Tektronix version has a spacing of 0.008 inch. Both CRT assemblies will be qualified under the F-15 program.

Figure 1 shows the packaging for the JTIDS/PACS MPCD. Figure 2 shows the packaging for the F-15E MPCD. The subassemblies are mounted to the bottom, side walls, or internal deck structure as shown. Coldwalls remove heat from the horizontal and vertical deflection amplifiers, which accounts for 60 percent of the total heal dissipation in the MPCP. A combination of coldwall and impingement cooling provides cooling for the other subassemblies. The CRT and yoke assembly shown in figure 5 contains the CRT, bandpass filter, deflection yoke, convergence yoke and purity/blue lateral assembly.

Typical color display formats are shown in figures 6 and 7. The color map system was flown on the F-15 as part of the Advanced Fighter Concept demonstrator program.

Sperry initiated a development program jointly with Tektronix of Beaverton, Oregon to develop a U.S. source for high resolution CRTs applicable to military programs. With the CRT being a critical component of the display, the development of a CONUS source for the shadow mask CRT seemed to be necessary for security reasons. The technologies developed by Tektronix have resulted in significant performance advantages over color CRTs of conventional shadow mask design. The CRT developed under this program was developed for the military environment and therefore exhibits superior vibration resistance, viewability in high ambient, raster presentations with higher resolution and higher brightness than any other avionic shadow mask CRT in the world.

The technical details of the Tektronix CRT are further defined in reference four. For comparison purposes with the Japanese CRTs some of the differences are as follows:

a) The CRT face is flat.
b) The funnel of the CRT is a pink beige and opaque and made of a special ceramic material.
c) The faceplate is clear instead of a neutral density filter and the screen appears to be gray and devoid of a dot pattern as in the conventional shadow mask CRTs.

The gray appearing screen is the result of the phosphor dot size and spacing which is two-thirds of the conventional high-resolution avionic shadow mask CRT and therefore below the discrimination threshold for normal vision at design eye distances of 28-30 inches. The electron gun is a delta design in order to help establish the very high resolution capability of the CRT as well as placing more energy on the CRT phosphor spots for improved brightness. The clear flat faceplate has a bonded-on multiple bandpass filter. The flat face eliminates parallax problems associated with a curved faceplate and filter combination. The clear faceplate virtually commits all of the generated CRT luminosity to the

selected filtering of the contrast enhancement filter. The ceramic CRT body provides for both x-ray attenuation and strength. With direct control over the shape of funnel and flare of the tube the manufacturer can contour the CRT to conform to a optimally designed and shaped deflection yoke for a small gain in deflection sensitivity. (See figure 8.)

Because the MPCD was going into a tactical fighter aircraft, particular attention was paid to the vibration characteristics and design in both CRTs and CRT assemblies. The Mashushita CRT was modified to improve its ruggedization. The Tektronix CRT was designed from the beginning with a military application in mind.

The vibration hardening of the Tektronix CRT was carried out in phases in which each major component of the CRT was independently designed and adapted to meet the stringent military vibration requirements. The approach taken was to treat the vibration dynamics of the CRT assembly as a system, which includes the resilient mount. Consequently, the natural resonance of gun and mask are tuned away from the relatively low frequency of the mount in order to reduce the response to energy transmitted through the CRT mount. Special shadow-mask spring and mount designs are required to counter both linear and torsional loadings imposed on the mask assembly during vibration. Direct electrical connection is made from the anode to the shadow mask in this CRT. Conventionally, the anode voltage is conducted to the shadow mask through snubber springs welded to the mask and resting in spring contact with the inner conductive surface of the CRT. The direct connection is incorporated to preclude the possibility of any "open" that might occur through spring-contact bounce or scrubbing at the contact point.

Many of the gun components are strengthened or reinforced in order to maintain proper geometry and centering in the gun end of the CRT during and after vibration at military levels. The CRTs have remained fully operational after endurance testing in the specially designed mounting system at levels in excess of 9 grms random for more than two hours per axis. The display can be operated at levels in excess of 5 grms random.

The unique construction of the Tektronix shadow mask makes possible the very high resolution of this CRT. In contrast to the domed shadow mask of the conventional CRT, the Tektronix design features a thin, flat, taut-foil mask that permits the formation of a dot pattern with two thirds the dot size and spacing of other high-resolution avionic shadow-mask CRTs. A specially designed support system is required to maintain the positioning of the shadow mask with sufficient accuracy and repeatiblity to permit the formation of the very high-resolution dot pattern. The mask design is complemented by a photolithographic process for the formation of the high definition black matrix background, and by a unique automasking process[5] for deposition of the actual phosphor dot patterns. The thin-film composition employed for the black background is optically matched at the glass interface to minimize the reflected light.

Conventional high resolution avionic CRTs have a dot spacing of .012 inch (0.3 millimeter). The very high resolution design has spacings of .008 inch (0.2 millimeter) and corresponding small phosphor dots. At normal pilot viewing distances the threshold of perception is at about one minute of angular subtense, about .008 inch at 28 inches. The dot pattern of this CRT is not perceptible at the usual viewing distances. The stairstepping usually associated with gently curving or slightly off-axis, stroke-written lines is noticeably reduced in this tube.

However, two of the most important assets of this very high-resolution CRT are associated with raster presentations. As shown in Table 1, the smaller geometries of the phosphor dot pattern permit a significant increase in the number of line pairs per inch resolvable in this display: 70 versus 50 for comparable modulation levels. A larger number of line pairs are possible provided the modulation requirement of the lines are reduced. At reduced brightness and modulation the Moire' limit of 90 line pairs per inch is possible. Putting it in slightly different terms, this new CRT will exhibit a greater depth of modulation (more detail contrast) than other high-resolution shadow-mask CRTs, given the same analog raster input from an airborne sensor. This is possible because smaller raster linewidths are usable in the very high-resolution tube. It is not simply the spacing between ranks of dots in the phosphor screen that limit the raster resolution for these CRTs. It is the more complicated Moire' limit, a brightness modulation phenomenon that is the result of interaction between the dot-pattern spacing, raster line spacing, and the linewidth of the raster lines. By analysis or by direct measurement, the linewidth below which Moire' interference patterns begin to appear on an otherwise unmodulated flat-field raster is approximately .016 inch (linewidth measured at the half-intensity points) for CRTs having .012-inch dot spacing, and about .011 inch for CRTs with .008-inch dot spacing.

The second major attribute of this CRT is its raster brightness capability. Where raster presentations are displayed on shadow-mask tubes, the brightness limit of the presentation is not always imposed by the ability of the electron gun to deliver a sufficiently large or adequately focused beam current to the screen. Rather it is the point at which the thermally induced dimensional changes in the mask create a loss of color purity in the display. This is readily demonstrated with CRTs of conventional shadow-mask construction at surprisingly low beam currents when a flat-field raster is displayed. Many conventional tubes will begin to lose purity at unmodulated beam currents on the order of 200 to 300 microamperes, less than 1/4 watt per square inch. As shown in the table, the Tektronix CRT is capable of in excess of 1 watt per square inch without loss of color purity. This corresponds to more than 1250 microamperes total beam current. These raster display characteristics are especially valuable in the display of sensor data in situations where there is relatively little contrast present in the imagery. Under these conditions, the background brightness of the display is usually increased to a level where the observer can be sure of seeing all the detail present against a relatively constant brightness background. The Tektronix CRT permits a much higher background brightness level than the conventional CRT to be set without encountering color purity loss in the presentation.

Contrast enhancement of the F-15 MPCD is accomplished with a single layer triple bandpass filter. The transmission characteristics have been designed such that a balance between display contrast and brightness is achieved. Displays using these filters have been demonstrated outdoors in direct sunlight of Arizona to observers from the Air Force and airframe manufacturers. The displays were readily readable with direct sunlight. The stroke symbology was totally discernible despite some color desaturation effects of the direct sunlight. The different colors of a raster color bar pattern were also discernible in sunlight, however the contrast levels are much lower than monochrome CRTs.

TABLE 1

COMPARISONS FOR 5-INCH X 5-INCH AVIONIC SHADOW-MASK COLOR CRTs
HIGH RESOLUTION VERSUS VERY HIGH RESOLUTION

PARAMETER	HIGH RESOLUTION	VERY HIGH RESOLUTION
Source	Japan	United States
Envelope	All glass	Glass and ceramic
Gun Type (Neck Size)	Delta (36 mm)	Delta (36 mm)
Phosphor Dot Pitch	.012 inch	.008 inch
Minimum Linewidth (Moire Limit)	.016 inch	.011 inch
Horizontal Resolution (10% MTF)	50 line pair/inch	70 line pair/inch
Purity Loss Threshold	1/4 watt/in^2	1 watt/inch^2

Advanced Color Display

Sperry has also cooperatively developed with Tektronix, a 6-inch by 6-inch usable screen shadow mask CRT using the same technology as the F-15 5X5 display. A demonstrator unit has been built and has performed very satisfactorily. The larger display was developed for many reasons, however two basic ones exist. The first is for the combination of display formats on one CRT. Current 5-inch color CRTs get too cluttered when a HUD type integrated presentation is placed on the CRT. The altitude, airspeed and heading information can be successfully combined with attitude information on the 6-inch CRT without reducing the symbology size to unusable levels or creating undue clutter. The usable screen area for the display increased by 44% from 25 square inches to 36 square inches. The second basic reason is for the use of the 6X6 shadow mask CRT as a sensor display. The resolution using a 10% raster modulation can provide a display with 420 discernible picture elements. If the modulation requirement is reduced and the ambient brightness/CRT brightness/spot size can be moderately controlled 480 discernible picture elements can be achieved which is the basic resolution of a 525 TV line system. The six inch very high resolution Tektronix CRT can be used for sensor presentation without seriously limiting the system resolution because of display limitations. In the case of a controlled environment, such as the rear of a S-3A, B-52, B-1, AWACS, etc., the display will not limit system resolution.

Sperry's Commercial Display Division has also developed an ARINC D size shadow mask color display with 6.7 inch by 6.7 inch usable area. The display is not as ruggedized as the military displays built by the Defense System Division, however it is being proposed for some of the C-130 foreign sales aircraft. The unit could be further ruggedized for special application or used as designed for benign environments.

Summary

Color CRT displays will become an accepted part of the military cockpit and in some cases the dominate feature of the crew station. The use of color displays in tactical presentations, threat displays, caution and warning, and map displays can reduce pilot workload and error rates. Additional testing is proceeding to determine if other quantitative benefits can be proven for other display applications such as ADI, HSI, etc. Almost all crew members indicate that they felt their performance was better with color displays. Many crew stations have had color displays for years with aviation red and aviation yellow, in addition to whites and blacks and many have used color electromechanical ADIs. Color in the cockpit will definitely increase in the future.

The color display for the F-15 is a significant step in the direction of high resolution color displays for the military cockpit. The advancements produced by Tektronix into very high resolution/high brightness shadow mask CRTs will increase the rate of incorporation of color CRTs into the cockpit. The ability of using a color CRT as the sensor display will further enhance the possibility of using one type CRT display in the Crew Station for reducing procurement, development, and logistics costs. Research work is being done to greatly increase the brightness of the color displays so that raster performance will approach current monochrome display performance. The all color CRT military cockpit is rapidly approaching reality as the commercial airlines have done in the 757/767 and A310.

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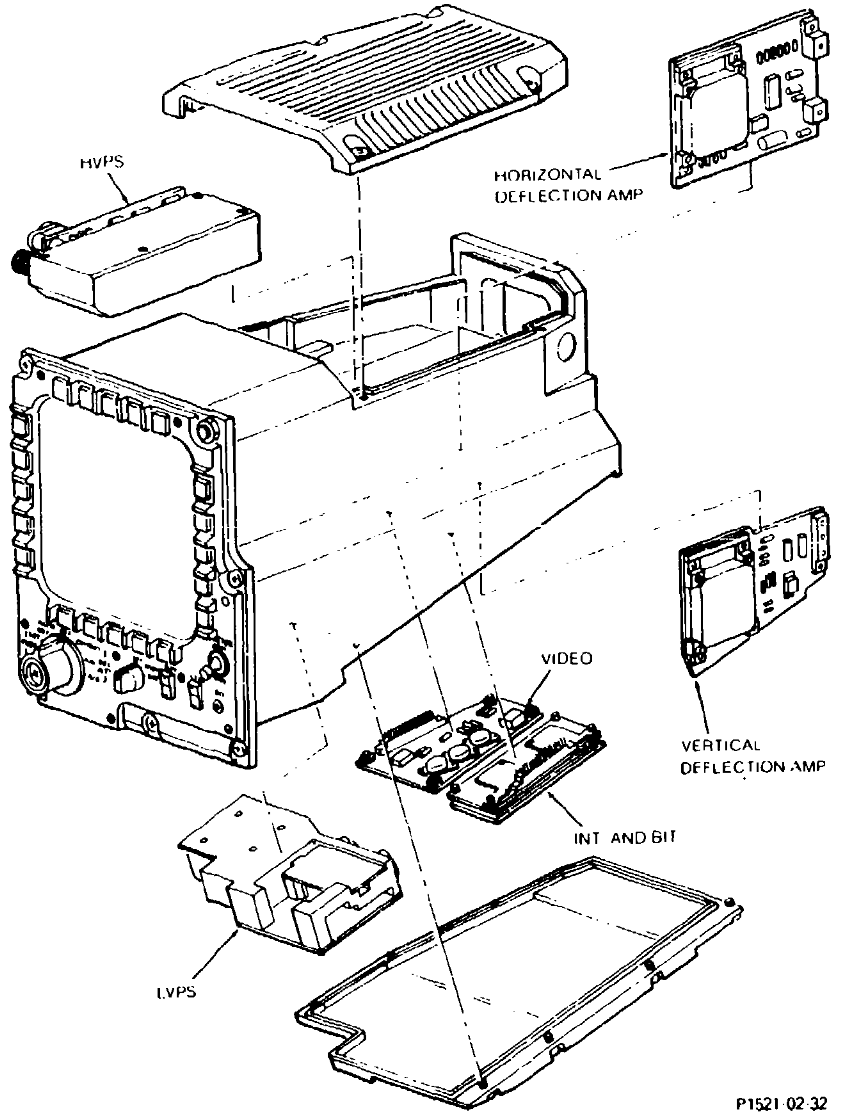
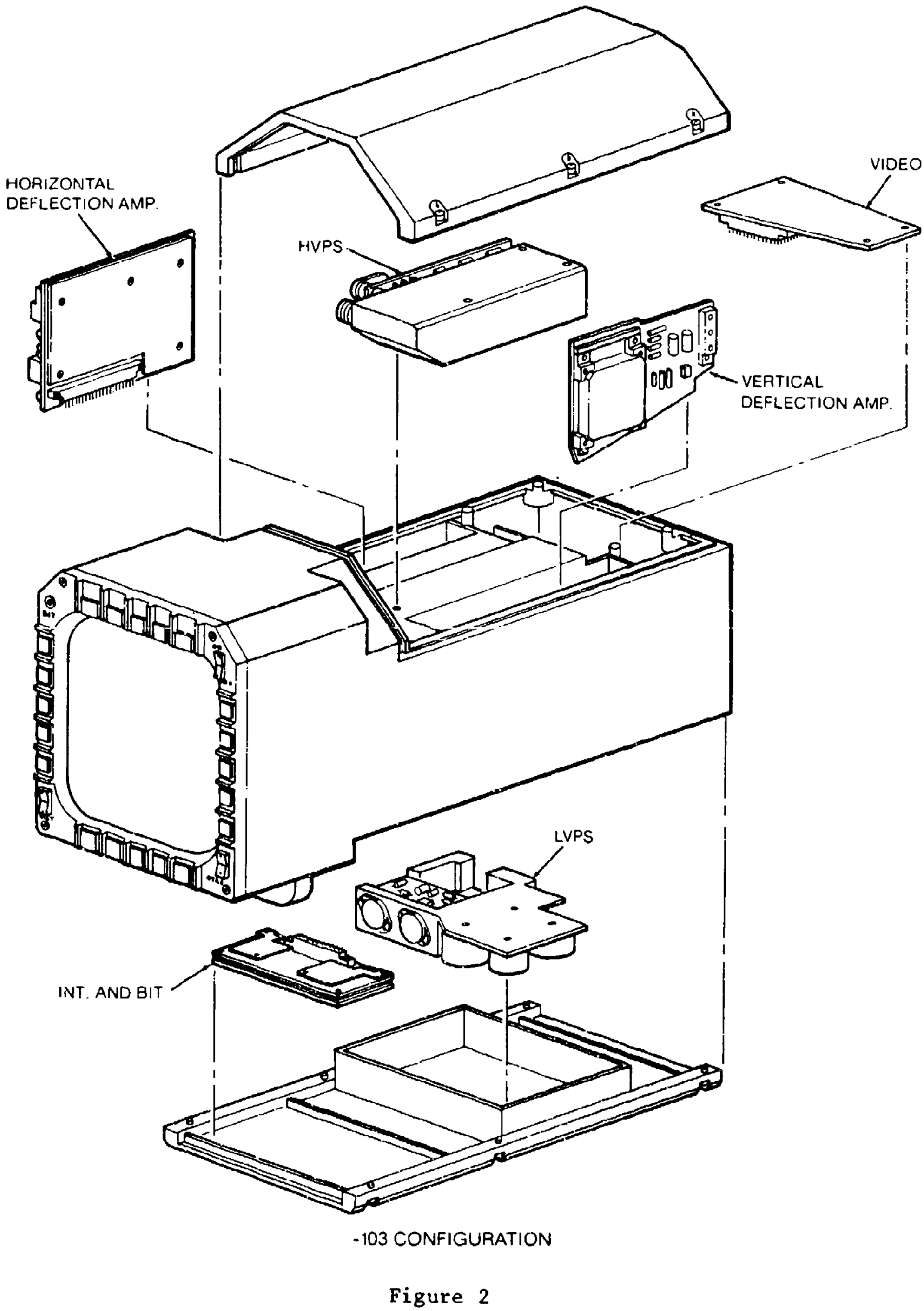

HVPS
HORIZONTAL DEFLECTION AMP
VIDEO
VERTICAL DEFLECTION AMP
INT AND BIT
LVPS
P1521-02-32

Figure 1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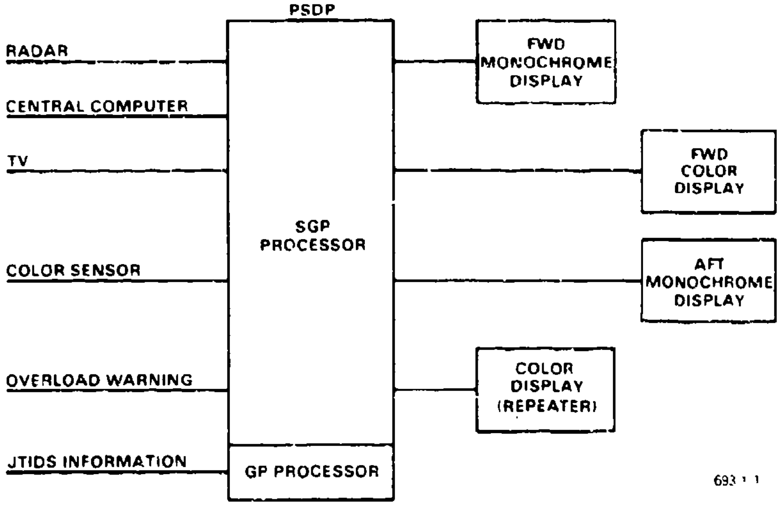
-103 CONFIGURATION

Figure 2



System Block Diagram

Figure 3

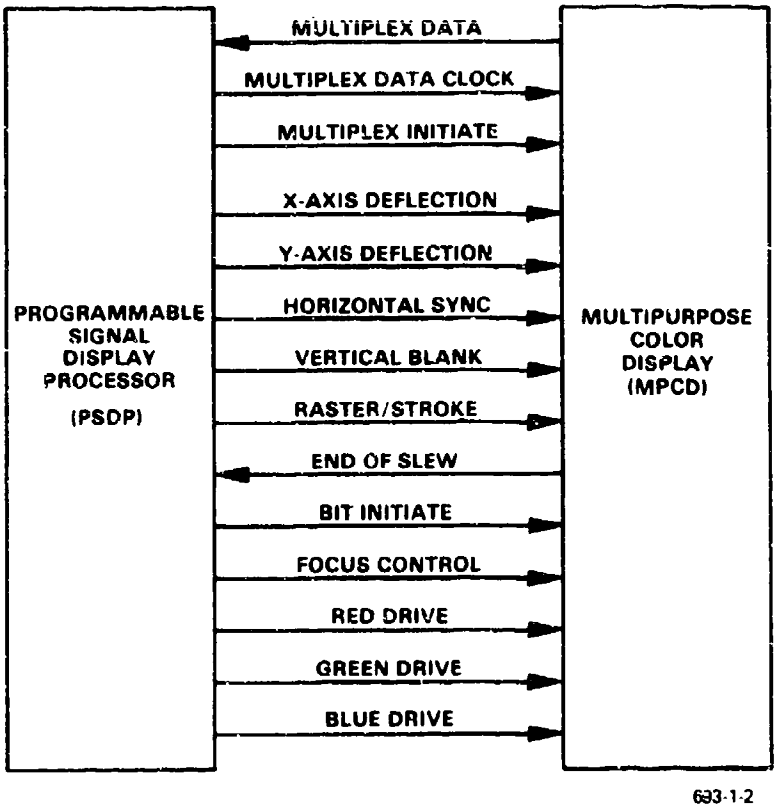


Figure 4

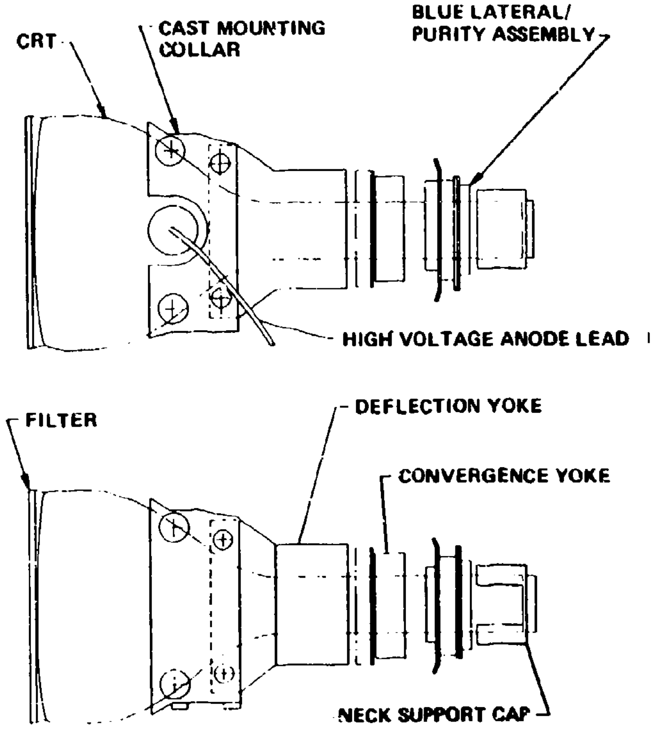

CRT
CAST MOUNTING COLLAR
BLUE LATERAL/ PURITY ASSEMBLY
HIGH VOLTAGE ANODE LEAD
FILTER
DEFLECTION YOKE
CONVERGENCE YOKE
NECK SUPPORT CAP

Figure 5

7 157' 1 12

Figure 6: JTIDS Format

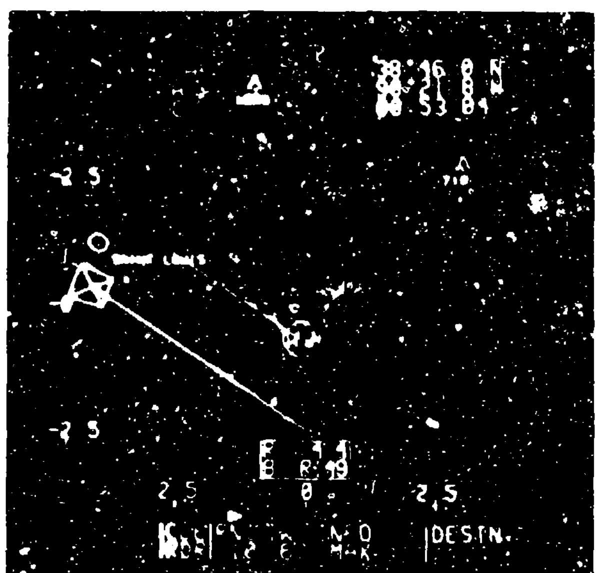


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Figure 7: Digital Map Format

SHADOW MASK CRT CONFIGURATIONS

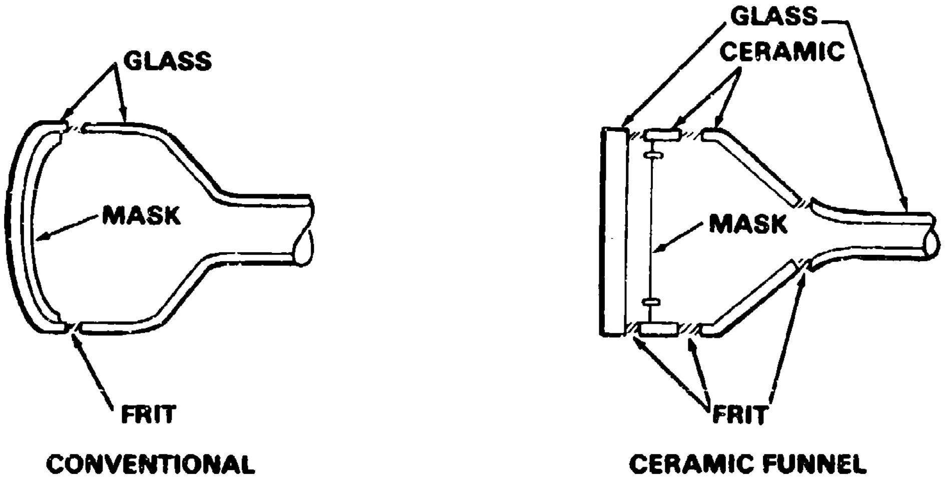
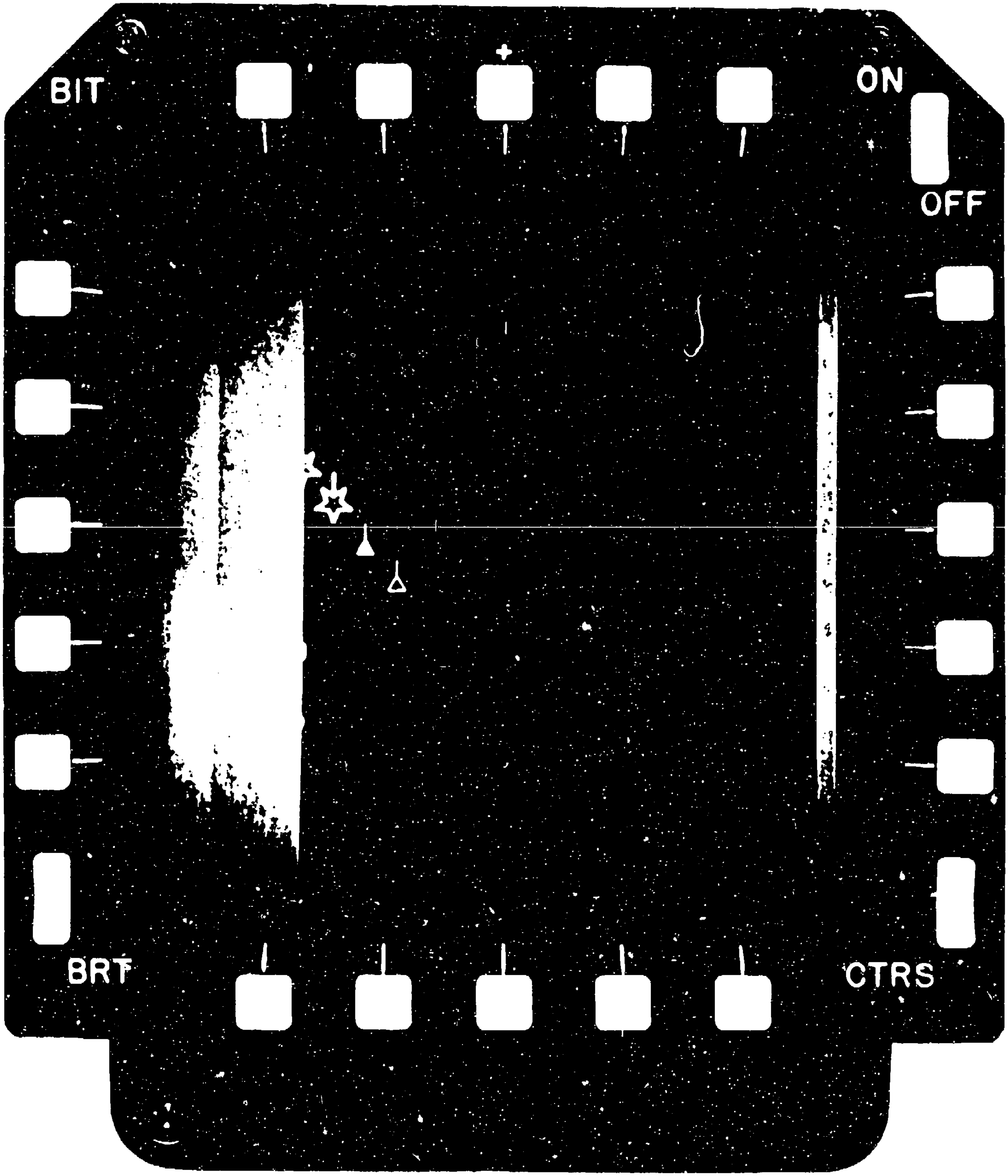


Figure 8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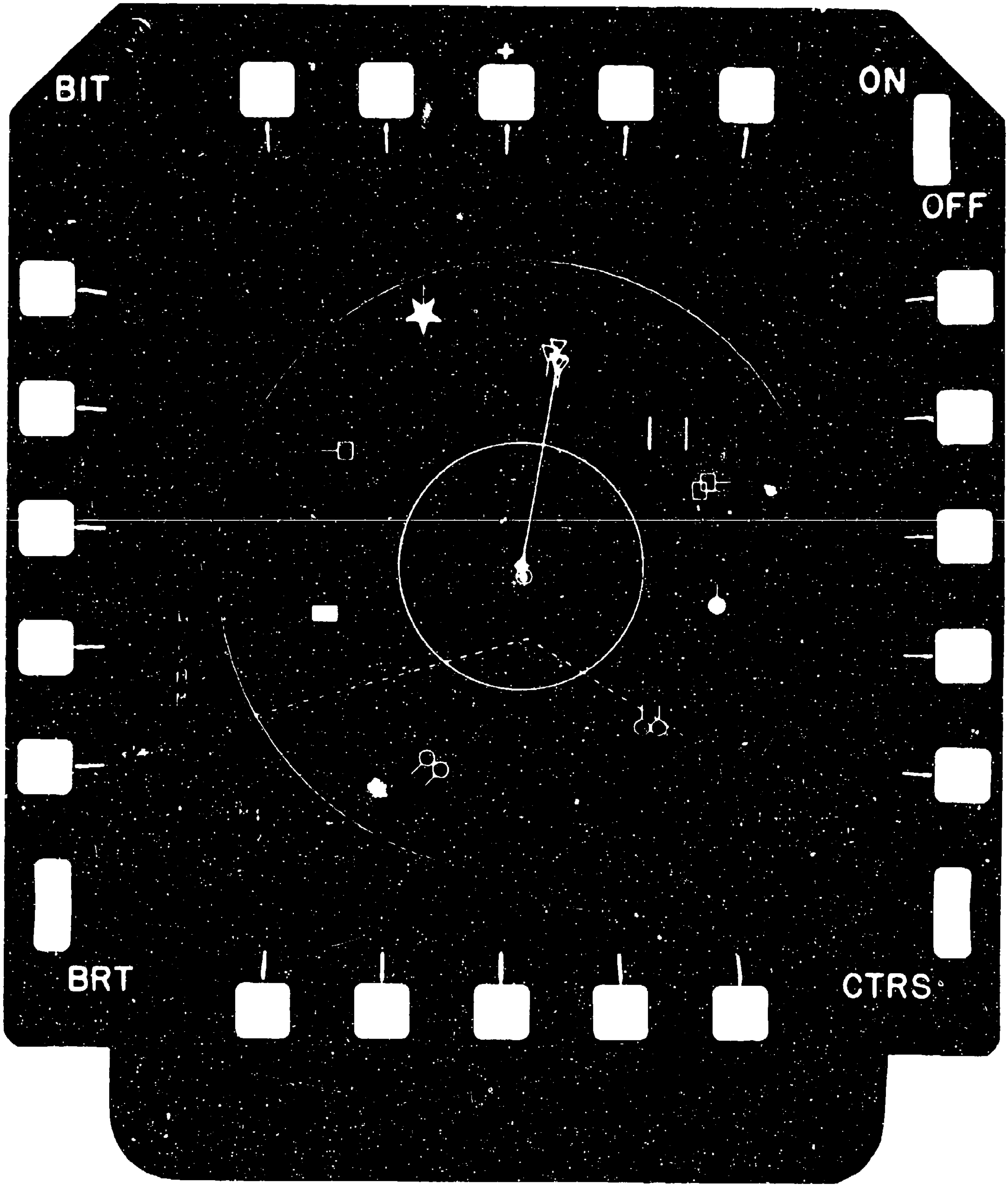
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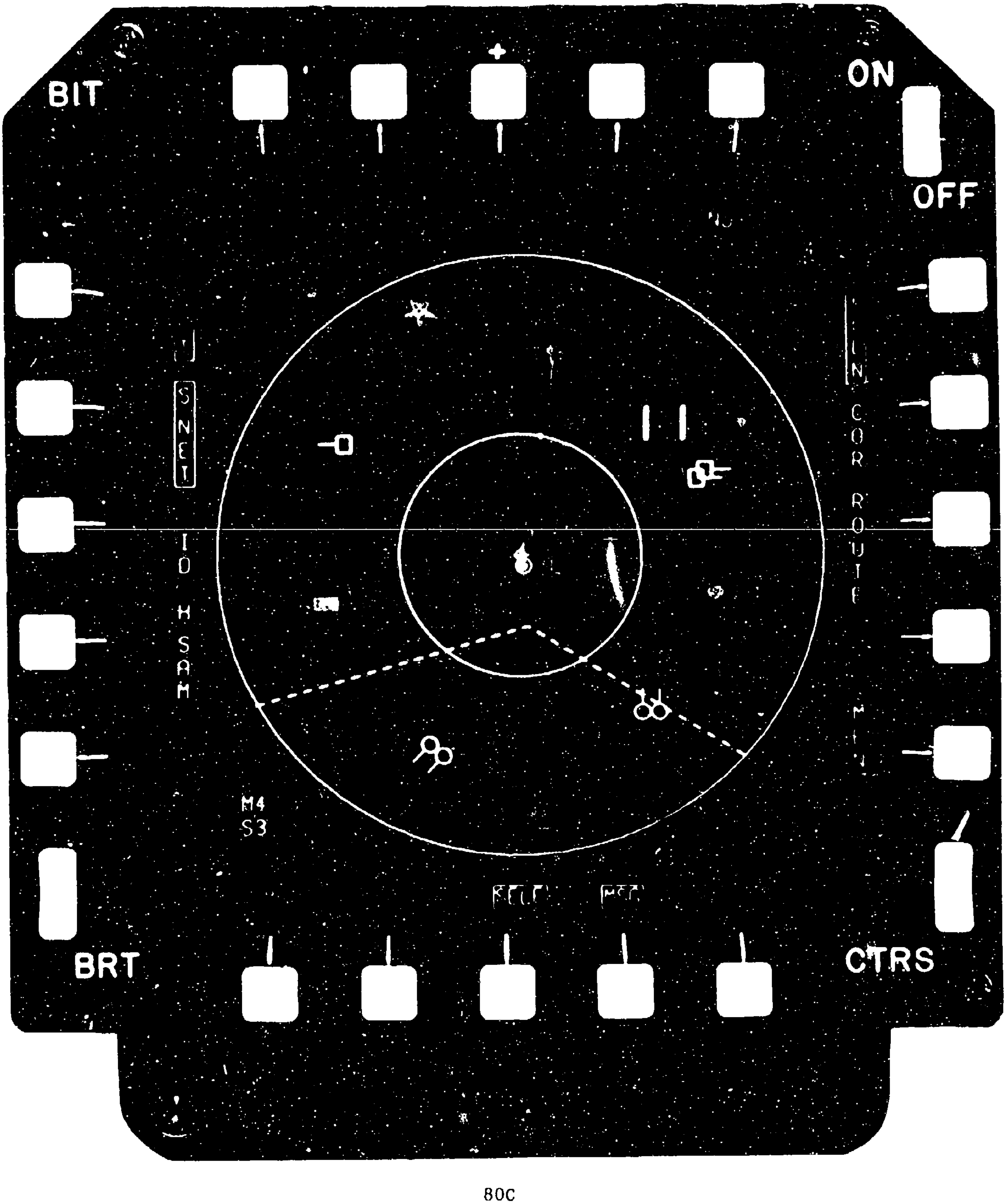

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INTEGRATION OF SENSOR AND DISPLAY SUBSYSTEMS

by

D. A. Bohrer and P. C. Jenkins

Presented by

Paul C. Jenkins

Systems Integration Engineer

and

Dean A. Bohrer

Air Force Programs Marketing Manager

Rockwell International

Collins Government Avionics Division

Cedar Rapids, Iowa 52498

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Naval Air Test Center

Patuxent River

INTRODUCTION

In recent years there has been much discussion about increasing crew workload in military aircraft caused by the proliferation of subsystems needed to satisfy operational requirements. Because of this and the parallel trend towards reduced crew complement and all weather day/night capability, a great deal of attention has been given to the use of multifunction control heads and electronic multipurpose displays to produce a more effective crew/avionics interface. However, if we take a wider view of a modern aircraft as a collection of interconnected subsystems and consider the integration of all subsystems with the same care that we currently apply to the man/machine interface we will produce an avionics system with excellent user characteristics plus:

- The ability to grow in an evolutionary manner.

- The ability to tolerate failures and damage.

- The ability to support enhanced self diagnostic and status reporting functions.

The process of system integration has been greatly facilitated by the development of military standards in interconnect media, stores interfaces, computers, and computer languages. This paper describes the evolution of our integration viewpoint, considers the drivers and candidate subsystems for integration and presents some examples drawn from our experience.

EVOLUTION OF INTEGRATION VIEWPOINT

Modern military aircraft typically contain a mixture of the following subsystems.

1. DISPLAYS

   - Flight Instrument ADI, HSI, etc.
   - Color/or monochromatic CRTs/flat panels
   - HUDs
   - Status Panels
   - Voice warning systems

2. NAVIGATION SENSORS

   - Inertial
   - Doppler
   - Radios - VOR, DME, TACAN, LORAN, etc.
   - GPS

3. MISSION RELATED SENSORS

- TV
- Infra Red
- Laser - Illuminator/Ranger/Designator
- Radar - Active/Passive
- Magnetic
- Acoustic
- SAR
- EW

4. COMMUNICATION

- Radios
- Satcom
- JTIDS
- PLRS
- Optical

5. COMPUTATION

- Navigation
- Weapons/fire control
- Tracking/Correlation
- Communication Management
- Aircraft diagnostic/status reporting
- Aircraft systems management - fuel engine parameters etc.
- Stores management

6. STORES

- Missiles
- Bombs
- Torpedoes
- ECM
- AFE

This long list only contains a sample of the functions which are currently specified and serves to illustrate the scope of an effective systems integration plan.

Decades ago technology dictated that only the most basic COM/NAV functions were available packaged on a function per box basis. Each of these functions was therefore a stand-alone item usually having a dedicated control/display interface with the crew.

More recently advances in electronics and the use of general purpose avionics computers have altered our view of the aircraft from a collection of boxes to a set of subsystems grouped by function. At this stage, however, these subsystems were still relatively isolated from each other and depended on the crew to ensure cooperative action. Crew workload increase therefore became a natural consequence of increased avionics complexity and capability.

Currently several military agencies and some aerospace contractors are taking a holistic approach to system design. Here the avionics system is conceived as a puzzle made up of functions and subsystems each of which have their place in the total operational 'picture'. Some interlocking pieces can stand alone in terms of a few very limited capabilities or the picture can grow as new pieces become available. The availability of these new components depends on funding, technology, and mission requirements, all of which are time related.

The ability to view not only what a system is, but also what it will become is an essential aspect of modern integrated design.

I will discuss the factors which demand this approach in a moment, but before proceeding it is worth briefly reviewing the integration tools which support the design, integration and verification process.

1. Multiplex Data Buses

   As illustrated in Figure 1 a multiplex data bus such as that defined by MIL-STD-1553 is simply a common cable which is connected to several terminals. Each terminal is assigned a digital 'address' which enables it to identify messages intended for its use. One of the terminals is designated 'bus controller' and has the duty of controlling access of each terminal to the common interconnect bus. Each terminal is assigned a time slot regularly so that it can communicate with other units on the bus. This process has the effect of replacing the bulky point to point physical wiring common in older aircraft with 'virtual wiring' where 'messages' conveniently take the place of physical cables.

   Obviously multiplex data buses provide tremendous flexibility for growth by avoiding the need to extensively rewire aircraft in order to incorporate new functions. There is a caveat however, any multiplex bus has a finite capacity for information and we must be aware of the percentage of that capacity currently utilized when planning for expansion. At Rockwell-Collins we recognized the need to control and analyze the message structure and capacity utilization of multiplex buses. We therefore developed a set of computer tools known as DBAS (Data Bus Analysis System) to support our systems integration activities. We anticipate an industry wide trend towards the use of such 'smart' support tools as system complexity continues to increase.

2. Multifunction Controls and Displays

   As participants in this symposium I am sure that we are all aware of the benefits provided by multifunction controls and displays. A great deal has been said about the use of color, new display technologies, and novel methods for interaction. However, from the systems integration viewpoint the principal benefit provided by these interactive media is the ability to design a standardized control sequence which is independent of the unit under control. For example, not long ago each radio had an associated control panel. Generally, the crew radio tuning actions depended on the radio being tuned. Now of course we are able to provide a standardized radio control sequence using multifunction control display units. This has the important consequence that we can change the physical implementation of radio, or the radio complement without having to retrain the crew.

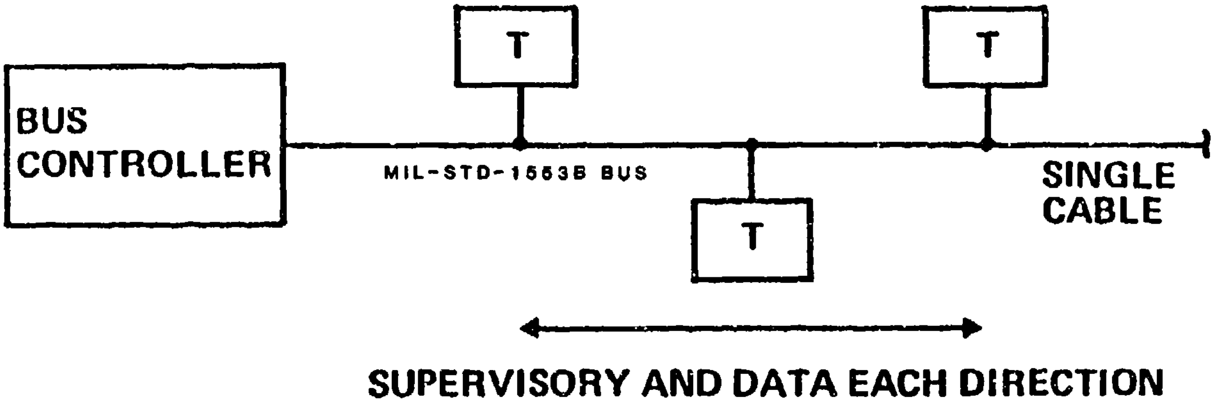

Figure 1. Multiplex Data Bus Conceptual Diagram

A second advantage is that growth in functionality does not always need additional control heads and resultant aircraft wiring modification.

3. Modularity

Trends in electronic packaging and software design have lead to the development of modules which can be assembled in a very flexible manner to create an avionics system. Design and development costs force us to avoid single application design solutions. Rather we develop new hardware and software modules which can then be added to our repertoire. I will talk about the use of these modules later, but now I want to consider the factors which necessitate holistic system design.

INTEGRATION DRIVERS

1. Mission Enhancement

The need to incorporate new functions, technologies, crew interaction mechanisms, weapons as determined by role or operational requirements.

2. Crew Workload

The need to provide a level of automation which allows crew to function as mission managers.

3. Graceful Growth

A combination of 1 and 2 above should ideally allow retrofit without extensive aircraft modification and crew retraining.

4. Graceful Degradation

System integrity considerations include identifying the survivability needs of the various components or subsystems and determining what role is played by multiplex bus management. How can partitioning, redundancy, and the use of reversionary modes be used to ensure system integrity?

5. Funding

Perhaps one of the most important roles of all is to provide the flexibility needed to allow the weapon system to be upgraded for changing requirements. Funding is getting tighter, yet technology is progressing at an ever increasing rate while the acquisition time appears to be lengthening. All of this only serves to increase the probability that threats will change before a weapon system becomes operational.

INTEGRATION CANDIDATES

Types of functions currently integrated include:

- CNI
- Stores
- Sensors
- Processors
- Controls
- Crew I/O

Even recently it is obvious that some integrators have lost sight of the integration drivers and have narrowed their focus on the integration candidates. Both users and manufacturers have drifted that way in the past.

THE CURRENT SITUATION

Three major events have manifested themselves over the past few years:

1. Acceptance of Multiplex Bus Architectures.
2. Powerful and Fast Microprocessors.
3. Multifunction Display/Input Media.

In the past we have not felt the dominance of these integration vehicles. Now, the acceptance of these fully developed capabilities gives us a chance to take a fresh look at the old and often ignored problem of the hodgepodge growth of aircraft systems.

Many of today's aircraft have avionics systems reminiscent of 1950's technology and, although providing an acceptable level of performance, this sort of system design has limited growth and enhancement opportunities.

How can the multiplex bus, microprocessors, and multifunction displays help us to solve this age old problem?

1. Standardized I/O has allowed us to essentially freeze I/O designs and be assured that future equipment will be directly compatible.

2. Microprocessor based systems have the capability to 'go back' and pick up existing functions. As an example consider the system illustrated in Figure 2 where standard modular units

    - Control Display Unit (CDU)
    - Bus Subsystem Interface Unit (BSIU)
    - Display Driver Unit (DDU)

    are used to provide the benefits of electronic instrumentation and multifunction control/display while utilizing largely 'conventional' avionic components. Indeed this capability is so powerful that it is

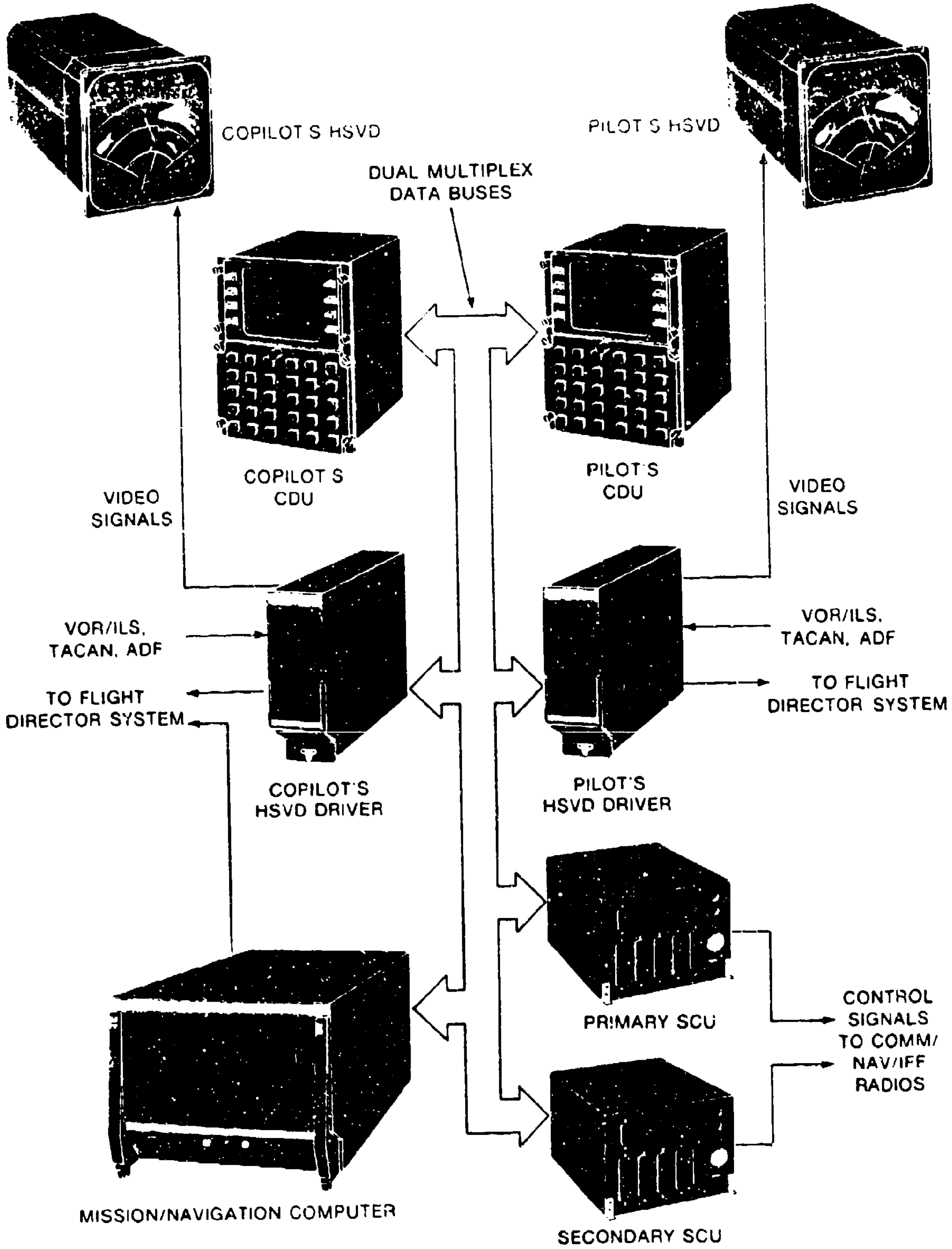

Figure 2. Multiplex System Incorporating Traditional Avionics

possible to retrofit existing aircraft with core multiplex systems which simultaneously provides for future rational growth--while allowing the retention of existing equipment. I will be talking more about this process which we have termed Retro-Evolution in a moment.

3. Displays have the capability to integrate a great deal of information and display it in a meaningful manner. Figure 3 is an example of one such typical display format.

EXAMPLE SYSTEM SOLUTIONS

1. EVOLUTION OF ROLE ADAPTABLE AIRCRAFT INSTALLATION

Core System:

The core of the system illustrated in Figure 4 is the multiplex system consisting of a multifunction CDU and an intelligent Bus Subsystem Interface Unit. The interfaced avionics fall into two categories:

a. Bus Compatible
   V/UHF Radio

b. Non Bus Compatible
   IFF
   Secure Voice Equipment

However, the crew is able to exercise multifunction control over all equipment since the control/display requirements of the non bus compatible equipment are satisfied by special Subsystem Interface Modules (SIMs) which when plugged into the BSIU mimic the conventional control head interface. The BSIU also contains corresponding software modules to support the SIMs and the control/display page structure.

The anticipated growth phases are also illustrated.

Phase 1 Growth:

In Phase 1, we see the addition of a non bus compatible multifunction radar. Here two principles are employed:

a. A SIM is used to provide full radar control via the multiplex bus. Initially, this control would originate at the CDU, but could also be provided by a future mission processor.

b. A monochrome Display Driver Unit (DDU) and display heads are added to provide radar display with overlayed symbology plus electronic ADI and HSI displays.

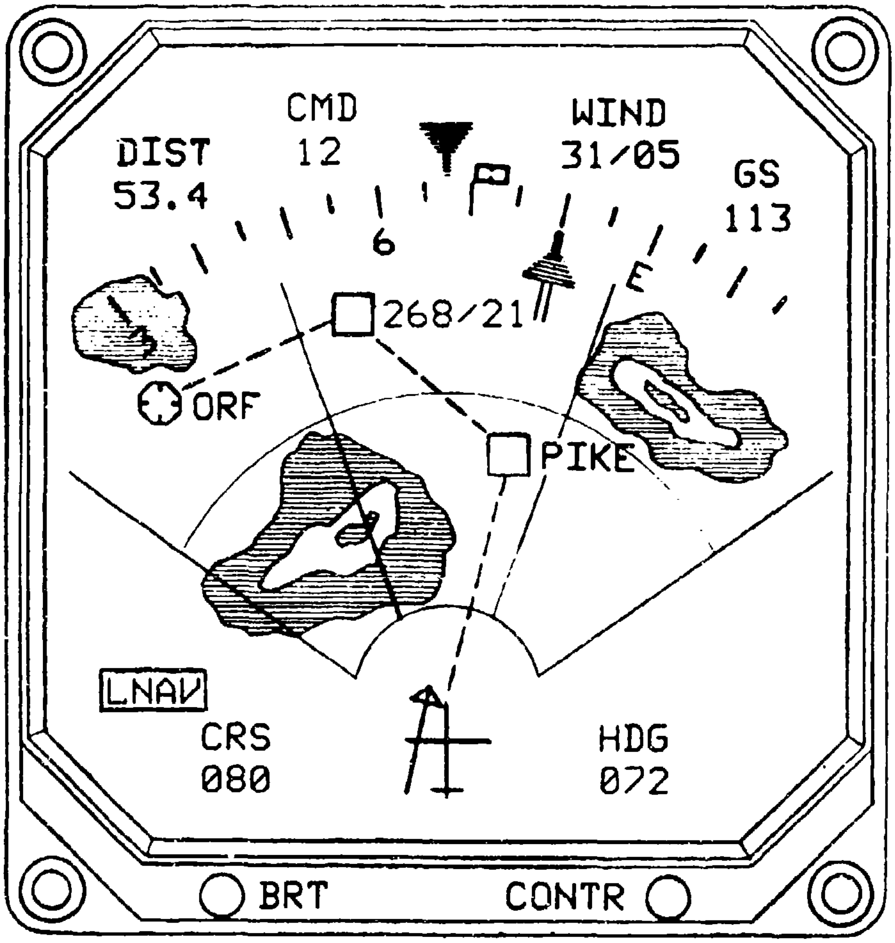

Figure 3. Typical Integrated Display Format

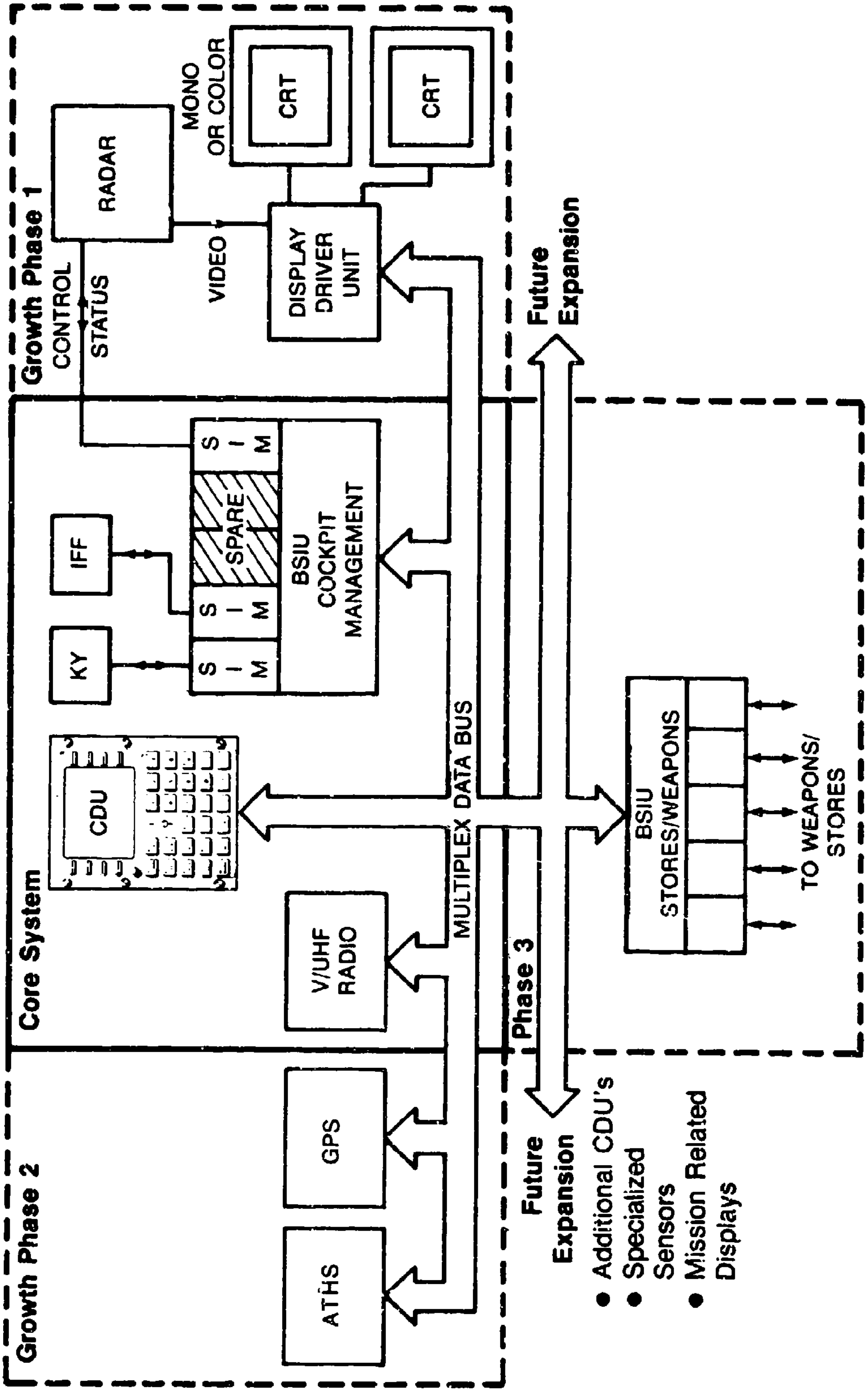

Figure 4. Evolution of Role Adaptable Aircraft Installation

Phase 2 Growth:

Phase 2 sees the incorporation of multiplex bus compatible GPS. No additional control heads are involved just additional CDU 'pages'. At this stage an Automatic Target Handoff System (ATHS) is also added. ATHS is a self-contained subsystem which generates its own set of CDU pages which enable the pilot to interactively classify and identify targets and digitally transmit/receive tactical information over a small local network. The multiplex bus interface enable ATHS to collect a great deal of data from connected aircraft sensors automatically with consequential pilot workload reduction. By utilizing existing voice radio channels for its burst tone modulated digital transmissions, ATHS has proved very effective in enhancing mission performance without the cost/space/power penalties usually associated with tactical networks like Link 11.

Phase 3 Growth:

Finally, phase 3 adds an additional BSIU acting as a stores management computer contain special stores interface SIMs.

2. AIRCRAFT SYSTEM RETRO-EVOLUTION

The first example considered how a communications control system could be designed to incorporate and support several aircraft systems. Here we consider an existing aircraft where cockpit space is severely limited and pilot workload is rapidly approaching saturation. In this case it is possible to take advantage of a retrofit opportunity to lay the foundation for future rational growth. This process is termed Retro-Evolution.

We assume a small cockpit equipped with a radar which has a dedicated monochrome display head, mechanical flight instruments and several manual radio control panels.

The objective of the core retrofit is to eliminate the mechanical flight instruments and replace the dedicated display head by dual color multipurpose displays.

This is accomplished by installing a Display Generator (DG) together with two multifunction displays. Subsystem Interface Modules (SIMs) are used as in the previous example to replace the existing radar control head. The radar control function is mechanized using software interpreted 'soft' keys surrounding the display heads. Radar video is routed to either or both displays via the DG. Interface Modules allow the DG to access all the sensor information previously available in the aircraft. It should be noted that this core system does not use the multiplex data bus, however, the core modification provides the following facilities:

- Dual Independent Displays
- Electronic Flight Instruments
- Waypoint navigation using computer embedded in DG
- Electronic tactical flight plan display and editing with optional radar overlay
- Overlay of flags and status symbols.

Phase 1 Growth:

The first enhancement phase is the addition of a remote map reader which is controlled and provided with positional information via the multiplex bus. Currently, this would be a TV scanned film unit, but in the near future digitally synthesized 2D/3D units will become available. This addition allows overlayed map, flight plan, and other symbology.

Phase 2 Growth:

Here the radio control panels are removed and their interfaces with the existing COM/NAV radios emulated by additional SIMs plugged into the Display Generator which also supports the radio management software. The panel space so liberated could be used to support a multifunction control/display unit (CDU). Alternately the 'soft' keys surrounding the displays could be used for radio management supported by a remote keyboard. Additionally the CDU could be augmented by a compatible voice recognition/synthesis unit. This phase provides:

- Uniform pilot/radio interface
- Preset and symbolic tuning
- Automatic tuning

while retaining traditional radios.

Phase 3 Growth:

Here the existing navigation system is enhanced by the addition of GPS. With preplanned expansion to GPS the navigation software within the DG would accept this new sensor with minimum modification.

Phase 4 Growth:

A self contained JTIDS unit is added which together with software in the DG enhances the tactical role of the aircraft. The color displays are used to present net derived data to the pilot.

Obviously these examples are greatly simplified neglecting redundancy for example but they do serve to illustrate that the flexibility of multiplex bus can provide an excellent foundation for preplanned product improvement for both new and existing systems.

Recent examples of Retro-Evolution applications include:

KC-135 Fuel Savings Advisory and Cockpit Avionics System for US Airforce
- Phased retrofit with fuel savings advisory core growing into a fully integrated 'glass' cockpit.

OH-58C Light Cavalry Helicopter for US Army
- Phased retrofit with reduced workload/enhanced capability in a very limited cockpit space. A radio management core system is currently undergoing planned growth to include:
  - Stinger Missile Control
  - Roof Mounted Sight/Laser Interface
  - Automatic Target Handoff System

Again the goal is a fully integrated cockpit.

CLOSING REMARKS

Two integration scenarios have been discussed and obviously a wide variety of other possibilities exist. We hope that these examples have illustrated the final erosion of traditional subsystem boundaries and the need to cross the borders of CNI, Stores, Displays, sensors in either direction.

Historically novel integrated display formats have been proposed which cross traditional subsystem boundaries. The extension of the Northrop Maneuvering Flight Path Display to include aircraft status information is one example. Computers and buses can allow us to achieve this level of display integration but these tools must be combined with a total system viewpoint to be fully effective.

This view is particularly important now with the accelerating pace of technological advance. The space required by the traditional ATR box can now be used to provide a multitude of functions. ICNIA (Integrated Communication Navigation and Identification Avionics) where advanced digital signal processing techniques are used to provide all CNI services in the frequency band between approximately 2 MHz and 2 GHz simultaneously within the same LRU. This trend to size reduction will increase as current VHSIC research bears fruit.

Additionally, the increasing sophistication of our enemy and of the weapons deployed against us, demand the development of new techniques including:

- Sensor data fusion
- Advanced interactive techniques, voice, sight, etc.
- Artificially intelligent mission management systems
- Automatic target classification, recognition and destruction.

Recently, as part of the Sikorsky ARTI team, we have been examining system architectures which will support these advanced functions. It has become evident that these future architectures can be evolved from our current designs in a methodical manner albeit with the use of faster multiplex buses and advanced electronics.

In conclusion, we believe that good holistic integrated system design, which is adequately supported by hardware and software tools, provides the following benefits:

- Crew workload reduction
- Reduced crew training
- Fast design, development, and deployment
- Rapid role/mission adaptation
- Rapid incorporation of new technology with minimum risk
- Rapid incorporation of new electronic instrumentation formats
- Optimized cost/capability profile.

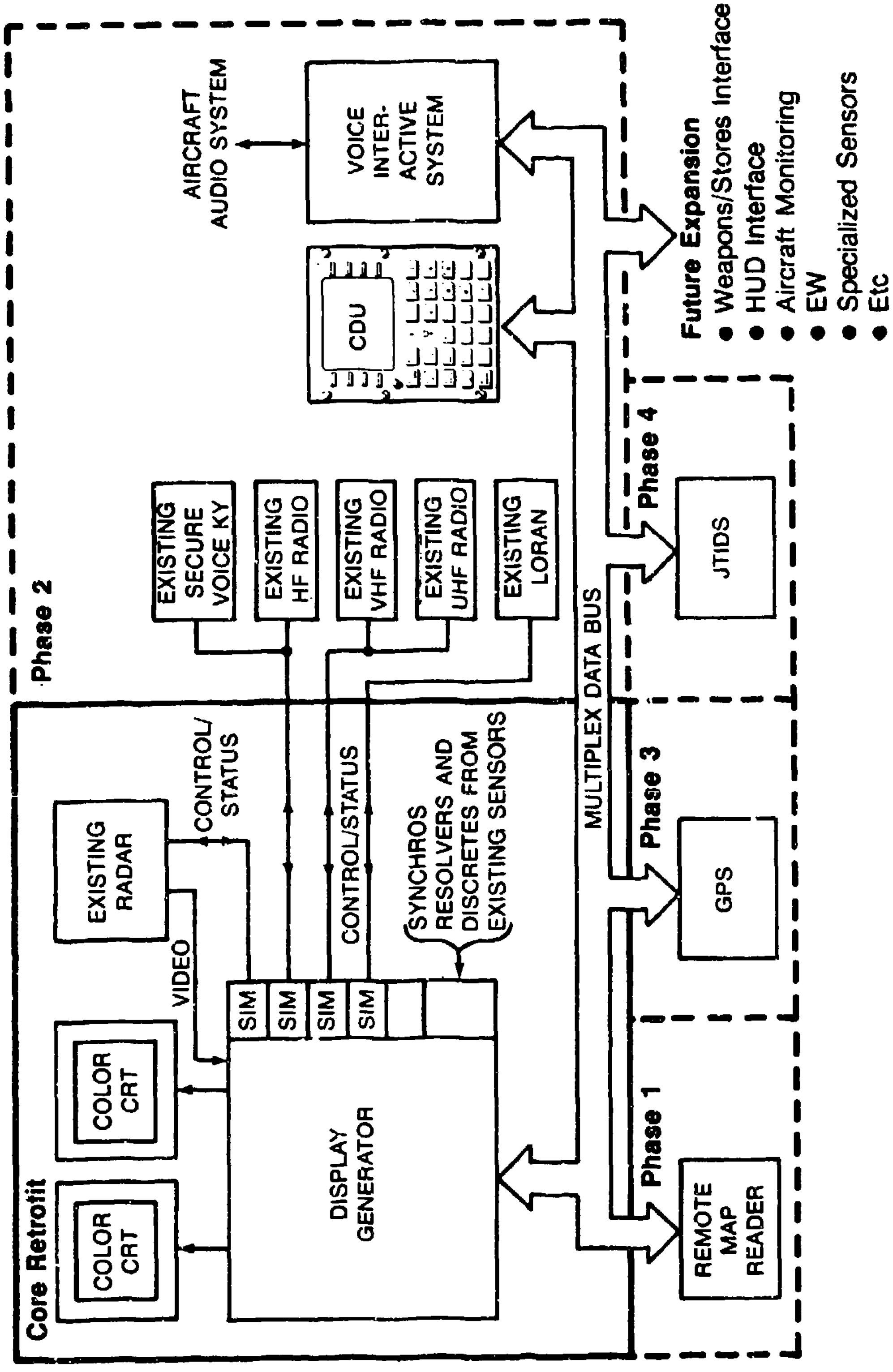

Figure 5. Aircraft System Retro-Evolution

MODERNIZING ENGINE DISPLAYS

by

Edward T. Schneider

and

Einar K. Enevoldson

National Aeronautics and Space Admini-.ration

Ames Research Center

Dryden Flight Research Facility

Edwards, California

10 May 1984

Introduction

The introduction of the electronic fuel control to modern turbine engines provides the user with a quantum increase in engine performance which reaches to the edge of the aircraft's operational envelope. To the fighter pilot, who more than all others, demands maximum performance and flexibility coupled with carefree engine operation, the electronic fuel control is truly significant. The problems associated with high angle of attack engine operation from the surface to 50,000 feet can be largely reduced, if not eliminated, by modern engine electronic fuel controls.

A spinoff of electronic fuel control technology is the vast amount of information which the fuel control can provide, if the proper engine displays are available to the pilot. This paper will explore some of the wealth of information available from modern fuel controls and hopefully stimulate your thinking as to improved engine display formats which will make use of the current technology.

Digital Electronic Engine Control

The electronic engine control systems which make possible both engine performance improvements as well as data availability are known in their most recent developmental forms as the Full Authority Digital Engine Control or FADEC and the Digital Electronic Engine Control or DEEC. These controls consist of a single digital channel with some internal redundancy. It has self test capability as well as failure detection and accomodation features.

It is the wealth of data available from the FADEC which is our primary interest in this discussion. Therefore, we will now look at the many bits of information which a modern electronic fuel control possesses and has available for display. The obvious parameters include engine mass air flows, engine compression ratio, fuel flows, and compressor and turbine speeds. Additionally, it has available, as input or output, internal temperatures at a variety of engine stations. The position of various internal components are also monitored. These include position of variable compressor vanes, nozzle position and area, bleed valve position, and the position of various intake components.

Additionally, the electronic control can detect engine compressor stalls, afterburner selection, and subsequent light-off or blow out. This is by no means a complete list of information available with an electronic control, but it provides the reader with an idea of the scope of data at hand.

Typical Engine Problems

Given such broad spectrum capability, one may ask what do we do with it all? The first application is to solve typical problems, which we should now review. Stall/stagnation problems come into the forefront during any engine discussion. These stalls range from the obvious to the subtle. The conventional, audible "bang" or "pop" of the compressor stall needs little introduction to the pilot. The less obvious quiet stall or stagnation more closely associated with today's turbofan tactical jet power plant frequently shows an insidious, hard to detect onset with potentially disasterous results. Here, warning the aircrew through use of displays becomes paramount.

Sometimes associated with the stall is the problem of variable inlet malfunctions. Modern high performance aircraft designs often require complex variable geometry inlets to allow for normal operation at very low as well as very high Mach numbers. Increased complexity has attendant reliability problems, which if they result in off schedule inlet operation can result in severe engine malfunctions.

Other problems which occur include total or partial failure of components as well as undetected malfunctions of normally governed components which allow for operation in a misgoverned condition. Last we have long term deterioration problems. An example would be reduction of stall margin due to blade wear or salt ingestion.

Solving Problems With Displays

Let's now look at two typical engine problems and see how modern displays turn data from the electronic fuel control into useful information for the aircrew. The occurrance of the engine stall will be unexpected, and

as was said earlier, the cues provided to the pilot will range from startling to undetected. Additionally, the cues provided by conventional engine instruments could be ambiguous with all parameters remaining in the normal operating range.

Frequently, stall interpretation requires correct analysis of multiple parameters: rpm, temperature, fuel flow, throttle responce, etc., in a rapidly changing situation. As if merely determining whether or not there is a problem isn't enough, corrective action normally must be prompt and it will depend on an entirely separate set of circumstances. Is there engine damage or is it just a simple malfunction? Is thrust needed immediately to prevent ground impact? Is the aircraft at high or low angle of attack? Has it departed controlled flight? Is someone shooting at you?

Through use of a modern electronic engine display we can get critical information fast. First of all the display can get our attention, it can announce the stall and give us the cause if known. Following this warning function the display can then list the options available to clear the stall. Such a list might include just waiting or a shutdown in a more severe case. If shutdown is required the display can tell us to either restart the engine or secure it, if warranted, by engine damage.

Another less severe problem may occur when operating the engine very close to the stall line when an engine component malfunction occurs. At this point the engine will very likely stall if the normally available options are exercised by the pilot. In this case the display could warn the aircrew against the marginal options such as lighting the afterburner, conducting high altitude slow speed flight, or reducing engine thrust to idle in certain regimes.

In both cases advanced engine displays can relieve aircrew of the need to interpret complex problems in critical situations; they can alert the pilot and provide him with a menu of corrective actions. All this can be done rapidly, reliably, and automatically.

Engine Displays in Normal Operation

The use of advanced displays is not limited to off nominal operations. These devices will provide significant improvements in the transmission of information during normal operating conditions as well.

In addition to the information available from current analog gauges, e.g., rpm, temperature, and fuel flow, other sophisticated computer calculated parameters are available. A modern engine display could provide the pilot a direct readout of thrust. This could be read as either an absolute value, or as a percentage of expected thrust for ambient conditions. For cruise tasks the display could also provide a readout of specific fuel comsumption.

When data from the aircraft's central air data computer (CADC) is used in conjunction with data from the digital fuel control even more information could be made available to the pilot. A readout of specific excess power, specific excess power per unit fuel flow, or nautical miles per pound of fuel could all easily be provided.

An Example Display Format

By now you have gotten the idea that the electronic fuel control can provide a real wealth of information, but the question now arises as to what kind of formats we may have in modern engine displays. Figure 1 is a naive pilot's idea of a modern format.

A typical modern display consists of a cathode ray tube (CRT) with on-half of the tube dedicated to each of two engines. On the left side of the tube we have an example of a stagnated engine. The display clearly announces the condition and presents the values of three key engine parameters: exhaust temperature, compressor speed, and fuel flow. Additionally, the fact that the fuel control is attempting to maintain minimum fuel flow to clear the stagnation is annotated.

NASA
DFRF83-637a

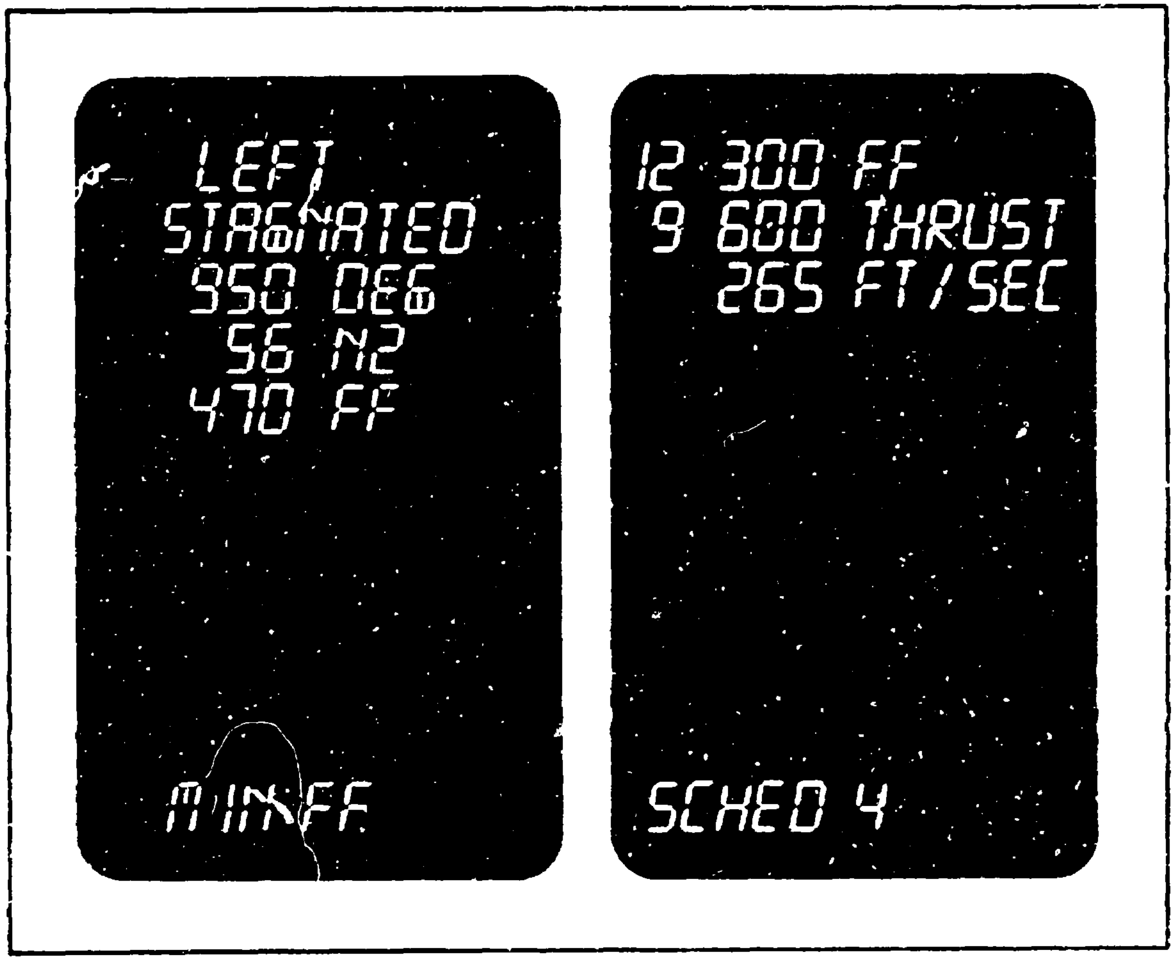

FIGURE 1: PROPOSED ENGINE DISPLAY

The right half of the CRT shows a normally operating engine. A traditional parameter, fuel flow, is shown along with two others. Thrust as well as specific excess power are displayed. At the bottom the use of the fourth airflow trimming schedule (or whatever subroutine the engine controller is operating in) is also shown.

Multi-Page Format

Within the automatic program available with the advanced engine display a multi-page format would be ideal for optimizing both the amount of and rapidity with which information is relayed to the aircrew. Page one would be the standard performance page, as exemplified by the right-half of figure one.

In the event of an emergency, page two, the emergency situation page, would automatically supersede the on condition display of page one. This page would identify the off-nominal condition; and then the DEEC would call up for display the immediate action emergency procedures to be carried out.

Page three, the diagnostics/health page, would be manually selectable by the aircrew. This page could provide a variety of internal engine parameters, e.g., turbine-inlet-temperature, various pressures, or any other raw data which the DEEC might know.

It is important that the engine display multi-page functions are automatic as much as possible to avoid burdening the pilot with the requirement to switch pages in an emergency. Manual selection of page three, however, would retain the flexibility to use this data when desired.

Flight Strategies

By now the use of a digital engine control coupled with an advanced display are obvious during an emergency situation. But how do we use the display during normal operation? If an air transport type flight computer is available, the electronic fuel control cal provide additional parameters to provide real-time updates to the computer, thus improving on the performance of these useful pieces of equipment.

For those aircraft without a flight performance computer, the electric fuel control can provide the aircrew with a comparison between different flight strategies to accomplish a task. For example, should a pilot use a higher power, less efficient fuel setting to do a task more quickly and save fuel? The electric fuel control can make a variety of parameters available and over time aircrew can develop a feel for the best way to perform a given task.

Hardware Considerations

Standard modern cockpit display hardware should be adequate for these proposed engine displays. No extra ordinary requirement for reliability exists for engine displays. They are not essential for safe rècovery of the airplane. it seems likely that the display should include some or most of the logic it embodies, and also contain enough processing capacity to present basic engine data in the event of failure of the engine electronic control.

Conclusion

The digital electronic fuel control coupled with an advanced engine display provides a large increase in the amount of engine performance information to the aircrew. These displays can assist the aircrew in both normal and emergency conditions and can provide optimum performance flight strategies. Modem display hardware could easily be coupled to the digital fuel control.

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SIXTH ADVANCED AIRCREW DISPLAY SYMPHOSIUM

COLORED DISPLAYS FOR COMBAT AIRCRAFT

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TEL. (1) [illegible] / TELEX TCSF 204 780 F

WEDNESDAY, 16 MAY 1984

THOMSON-CSF
DIVISION
EQUIPEMENTS AVIONIQUES

COLORED DISPLAYS FOR COMBAT AIRCRAFT

A PRESENTATION OF

THOMSON CSF SYSTEMS EVOLUTION
SINCE 1970 AND IN THE PERSPECTIVE OF 1990 s

HOW AND WHEN

HAS BEEN MADE, STEP BY STEP, THE IMPLEMENTATION OF COLOR DISPLAYS ON BOARD FRENCH NEW COMBAT AIRCRAFT

BESIDES

THE INTRODUCTION OF COLOR ON BOARD OTHER CATEGORIES OF AIRCRAFT

THOMSON-CSF
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PRESENTATION SUMMARY

1. OVERVIEW OF THE FIRST FRENCH COLOR DISPLAYS DEVELOPMENTS (1970 TO 1975)
2. PENETRON CRT TRICOLOR DISPLAY AIRCRAFT PROGRAMS
3. SHADOW MASK CRT MULTICOLOR DISPLAY AIRCRAFT PROGRAMS
4. TRENDS FOR THE NEXT GENERATION OF COMBAT AIRCRAFT

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1. OVERVIEW OF THE COLOR DISPLAYS DEVELOPMENT BEGINNINGS (1970 TO 1975)

HOW AND WHY IT STARTED ?

IN SEVERAL COUNTRIES, THE IDEA EMERGES AROUND 1970
OF USING, ON BOARD AIRCRAFT
CRTs NOT ONLY FOR RADAR RAW DATA PRESENTATION
BUT ALSO FOR FOR THE DISPLAY
OF MORE EXTENSIVE PILOT INFORMATION

HOWEVER AT THIS TIME MONOCHROME RASTER
DISPLAYS DEVELOPED HERE AND THERE SHOW MOSTLY
DATA PRESENTATION OF POOR QUALITY

FOR MORE ERGONOMIC DATA PRESENTATION THOMSON CSF
AVIONICS DIVISION DECIDES TO EXPERIMENT
THE POSSIBILITIES OFFERED BY COLOR "PENETRONS"CRTs
AS BY THIS TIME THEY ARE UNDER DEVELOPMENT
BY THOMSON CSF TUBES DIVISION

COLOR CODING

"PENETRONS" CRTs RETAIN TWO PHOSPHORUS LAYERS ONE RED, ONE GREEN. MODULATION OF EXCITATION OF THE PHOSPHORUS GIVES TO THE EYE THE PERCEPTION OF EITHER RED OR GREEN OR OF YELLOW WHEN BOTH ARE EXCITED SIMULTANEOUSLY

SO ONLY THREE COLORS ARE USABLE FOR CODING , BUT THE INTERVAL BETWEEN THEIR WAVE LENGTHS OR MORE GENERALLY BETWEEN THEIR POSITION ON THE C.I.E. COLORS DIAGRAM IS WIDE ENOUGH FOR A GOOD CHROMINANCE VISUAL CONTRAST, WHICH IS IN ANY WAY BETTER THAN THE CHROMINANCE CONTRAST WHICH MAY BE OBTAINED WHEN USING A GREATER NUMBER OF COLORS

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DEVELOPMENT MILESTONES

1970-71 FIRST BREADBOARD OF A COLOR ELECTRONIC ATTITUDE DISPLAY INDICATOR (CEADI) , SOON AFTER , TO COUNTER A TENDENCY TO CLUTTER THE CEADI WITH TOO MANY DATA , ADDITION OF A COLOR ELECTRONIC MULTIFUNCTION DISPLAY INDICATOR (CEMDI) TO BE USED SIMULTANEOUSLY

1972 TAKING INTO ACCOUNT THE POSITIVE RESULT OF THIS EXPERIMENTATION OF A CONCEPT, CRTs TECHNICAL CHARACTERISTICS ARE UPGRADED ... TO PREPARE FOR IN FLIGHT TESTING, LUMINANCE IS INCREASED BY CRT HIGH VOLTAGE INCREASE FROM 6 TO 12 KV UP TO 11 TO 17 KV

1973 THE FIRST EXPERIMENTAL COLOR ELECTRONIC PANEL FOR AIRLINER IS PRESENTED AT LE BOURGET 1973 AIRSHOW

1974 FOR MILITARY APPLICATION, HYBRID PENETRON COLOR DISPLAY ALLOWING SUPERIMPOSITION OF COLOR STROKE SYMBOLOGY OVER MONOCHROME RASTER IMAGE

AT THE SAME TIME PENETRON CRT HIGH VOLTAGE INCREASES AGAIN UP TO 21 KV BEFORE GOING TO 23 KV

1975 THE NASA IN CONJUNCTION WITH THE EUROPEAN SPACE AGENCY PLACES THE FIRST ORDER FOR PENETRON COLOR DISPLAYS FOR FLIGHT DATA PRESENTATION ON BOARD THE SPACE LAB

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2 TWO MILITARY AIRCRAFT PROGRAMS WITH , FOR THE FIRST TIME , ELECTRONIC COLOR DISPLAY SYSTEMS

THEY ARE LAUNCHED AROUND 1976, THAT IS TO SAY, JUST AT A TIME WHEN THE THOMSON CSF "PENETRONS" PENETRATION COLOR CRTs DEVELOPMENT IS ARRIVING TO A LEVEL SUFFICIENT TO ENVISAGE THE USE OF THESE PENETRONS FOR MILITARY AIRCRAFT ELECTRONIC DISPLAY

THEY ARE

- A MARITIME PATROL AIRCRAFT PROGRAM
  THE ATLANTIC M2 PROGRAM
- A COMBAT AIRCRAFT PROGRAM
  THE MIRAGE 2000 PROGRAM

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WHY SUCH CHOICES ?

ON BOARD A MARITIME PATROL AIRCRAFT

COLOR CODING ADDED TO SHAPE CODING OF SYMBOLS IS VERY SUITABLE FOR TACTICAL SITUATION SYNTHESIS PRESENTATION,

PENETRATION CRT TECHNIC ALLOWS TO INTRODUCE NOT ONLY DIFFERENT COLORS BUT DIFFERENT PHOSPHORUS LUMINANCE DECAY TIMES ALSO VERY SUITABLE FOR A NEAT SIMULTANEOUS PRESENTATION OF

- TRACKED MOVING MOBILES
- RAW RADAR DATA

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ON BOARD A FIGHTER

THE ADDITION OF COLOR CODING TO SHAPE CODING ALLOWS A DECREASE IN THE DELAY OF OPERATIONAL DATA VISUAL ACQUISITION AND IN THE SAME TIME A DECREASE IN THE RISK OF MISINTEPRETATION .

IT IS ESPECIALLY BENEFICIAL AS DURING COMBAT ACTION OR TRANSIT IN OPERATIONAL ZONE EVERY THING IS GOING ESPECIALLY FAST

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IN THE CODE RETAINED BY FRENCH AIR FORCE FOR
MIRAGE 2000 COLOR CODE

- RED IS FOR SAFETY RELATED DATA PRESENTATION
- GREEN FOR MEASURED ON BOARD FLIGHT PARAMETERS
- YELLOW FOR SYSTEM COMPUTED TACTICAL DATA

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ADDITIONAL REMARK

ABOUT COLOR DISPLAY
INTEGRATION IN MIRAGE 2000 COCKPIT

WITHOUT COLCR CODING,PRESENTATION OF USEFUL
PARAMETERS WOULD HAVE REQUIRED A SPATIAL
DISPATCHING OVER SEVERAL SCREENS
FOR AN AIRCRAFT AS SLIM AS MIRAGE 2000
THIS WOULD NOT BE AS SUITABLE AS THE CONCENTRATION
OF TACTICAL SYNTHESIS ON A CENTRAL COLORED SCREEN

3 SHADOW MASK CRT MULTICOLOR DISPLAY AIRCRAFT PROGRAMS

3.1 AROUND 1977-78 IT APPEARS THAT JAPANESE SHADOW MASK CRTs ARE USABLE FOR CIVILIAN AIRCRAFT PROJECTS FOR ELECTRONIC FULL COLOR PANEL INSTRUMENTATION

AT THE END OF THE SEVENTIES TWO PROGRAMS ARE LAUNCHED, FIRST BY BOEING FOR THE BOEING 767-737 THEN BY AIRBUS INDUSTRY FOR THE AIRBUS A310

THOMSON CSF WINS THE CONTRACT FOR THE AIRBUS A310

THE INTRODUCTION OF THE NEW COLOR CRT
MARKS THE BEGINNING OF A NEW ERA CHARACTERIZED
BY A WIDENING COMPETITION
IT ALSO PREPARES NEW DEVELOPMENTS
FOR THE MILITARY APPLICATIONS

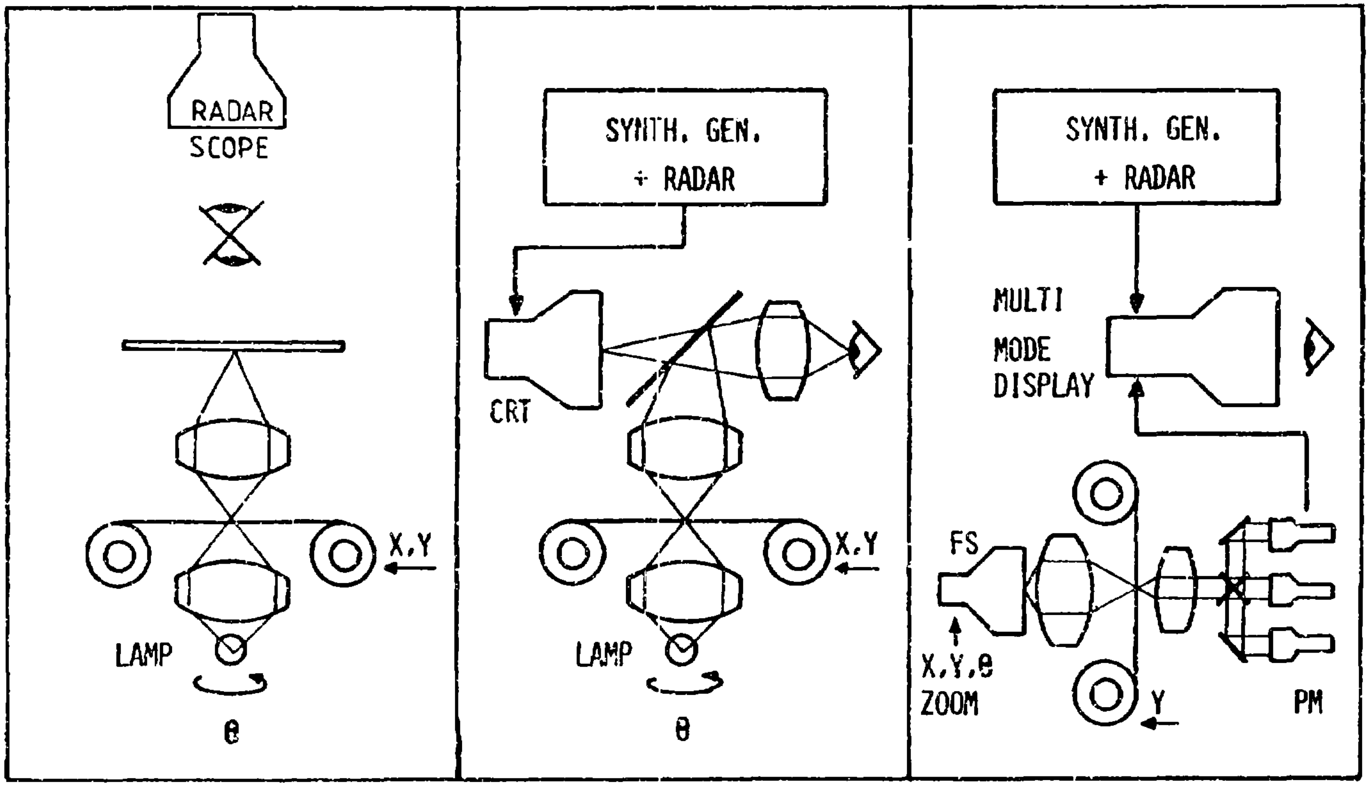
3.2 AT ABOUT THE SAME PERIOD, AROUND 1979,
THE FRENCH AIR FORCE ISSUES A REQUIREMENT
FOR A NEW PROJECT : THE MIRAGE 2000 N PROGRAM

THIS AIRCRAFT WILL HAVE TO BE ABLE TO CARRY OUT LOW LEVEL
PENETRATION STRIKE MISSIONS,
FOR THIS,IT WILL BE A TWO SEATER,IT NEEDS THE BEST
NAVIGATION DISPLAY SYSTEM FOR ACCURATE LOW LEVEL
TARGET ZONE TRANSIT

→ THOMSON CSF MAKES A PROPOSAL FOR A TWO
COCKPIT ELECTRONIC DISPLAY SYSTEM
THIS WILL PROVIDE,IN FULL ELECTRONIC MANNER,
THE DISPLAY OF MAP PRESENTATION,THE DISPLAY
WILL BE MULTICHROME
THIS IS THE "ICARE" SYSTEM

MAP DISPLAY EVOLUTION

1st GENERATION TH-CSF INCA	2nd GENERATION	3rd GENERATION TH-CSF ICARE
FUNCTIONAL SEPARATION	OPTICAL COMBINATION	ELECTRONIC INTEGRATION



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FILM ANALYSER - BAF

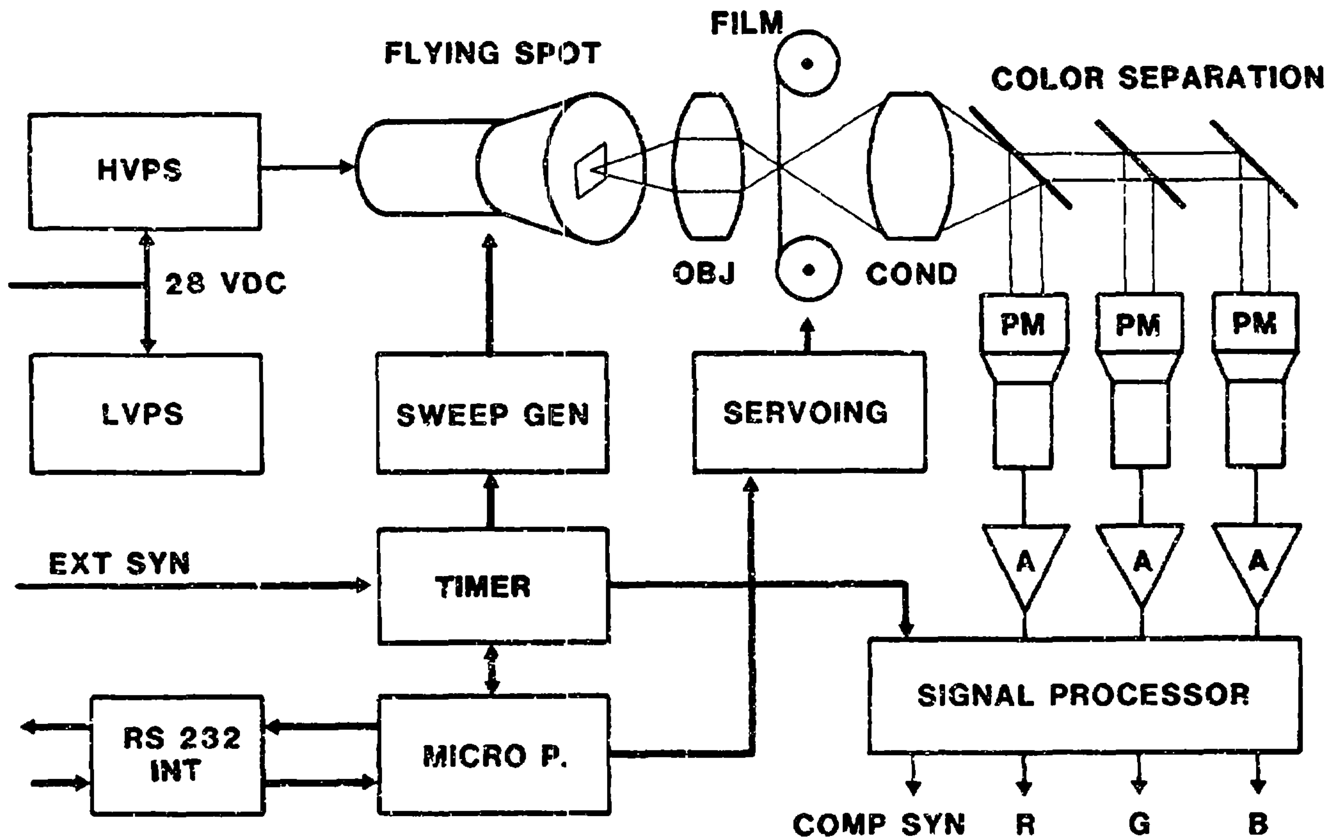

FIG.5

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REMOTE MAP READERS

1983 THOMSON CSF RMR LEADERSHIP HAS LED TO TWO MAJOR US CONTRACTS

MERCATOR FETE PROGRAM STUDY AND MANUFACTURING OF TWO MERCATOR REMOTE MAP READERS AND ASSOCIATED SIMULATORS FOR LAB EVALUATION/SIMULATION AT W.P.A.F.B AND FLIGHT TESTS AT EGLIN.AFB

THIS PROGRAM STARTED IN MARCH 1983 AND THE TWO PROTOTYPES ARE DUE TO BE DELIVERED TO W.P.A.F.B BY MID SEPTEMBER 84

MERCATOR LICENSE IN AUGUST 1983 THE MERCATOR LICENSE WAS SOLD TO HAMILTON STANDARD (UNITED TECHNOLOGY) A PROPOSAL WAS SUBMITTED TO GD DURING SUMMER 83 IN ORDER TO SUPPLY THE F 16 E WITH A MERCATOR RMR

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EQUIPEMENTS AVIONIQUES

4 TRENDS FOR THE NEXT GENERATION OF COMBAT AIRCRAFT

FOR DISPLAY SYSTEMS
FROM THOMSON CSF POINT OF VIEW
TWO GUIDELINES SEEM WORTH FOLLOWING

TO KEEP ON TRYING TO TAKE AS MUCH ADVANTAGE AS POSSIBLE FROM USE OF COLOR

TO REVIEW, AS OFTEN AS NECESSARY, THE FUNCTIONAL OVERALL CONCEPTS OF DISPLAY SYSTEMS SO AS TO FULLY MATCH THE FORESEEABLE TRENDS IN OPERATIONAL REQUIREMENTS

THOMSON-CSF
DIVISION
EQUIPEMENTS AVIONIQUES

IMPLEMENTATION OF THE FIRST GUIDELINE

MEANS THAT THE INTRODUCTION INTO OPERATIONAL USE OF THE MIRAGE 2000 M MULTIFUNCTION COLOR DISPLAY AND OF THE MIRAGE 2000 N "ICARE" COLOR ELECTRONIC MAP READER SYSTEM

IS ONLY A BEGINNING

BEFORE THE FURTHER ARRIVALS OF OTHERS COLOR DISPLAY SYSTEMS,GAINING ADVANTAGE FROM THE NEW TECHNICAL DEVELOPMENTS WHICH MIGHT OCCUR IN THE NEAR FUTURE AS WELL AS FROM THE ACCUMULATION OF IN FLIGHT EXPERIMENTATIONS

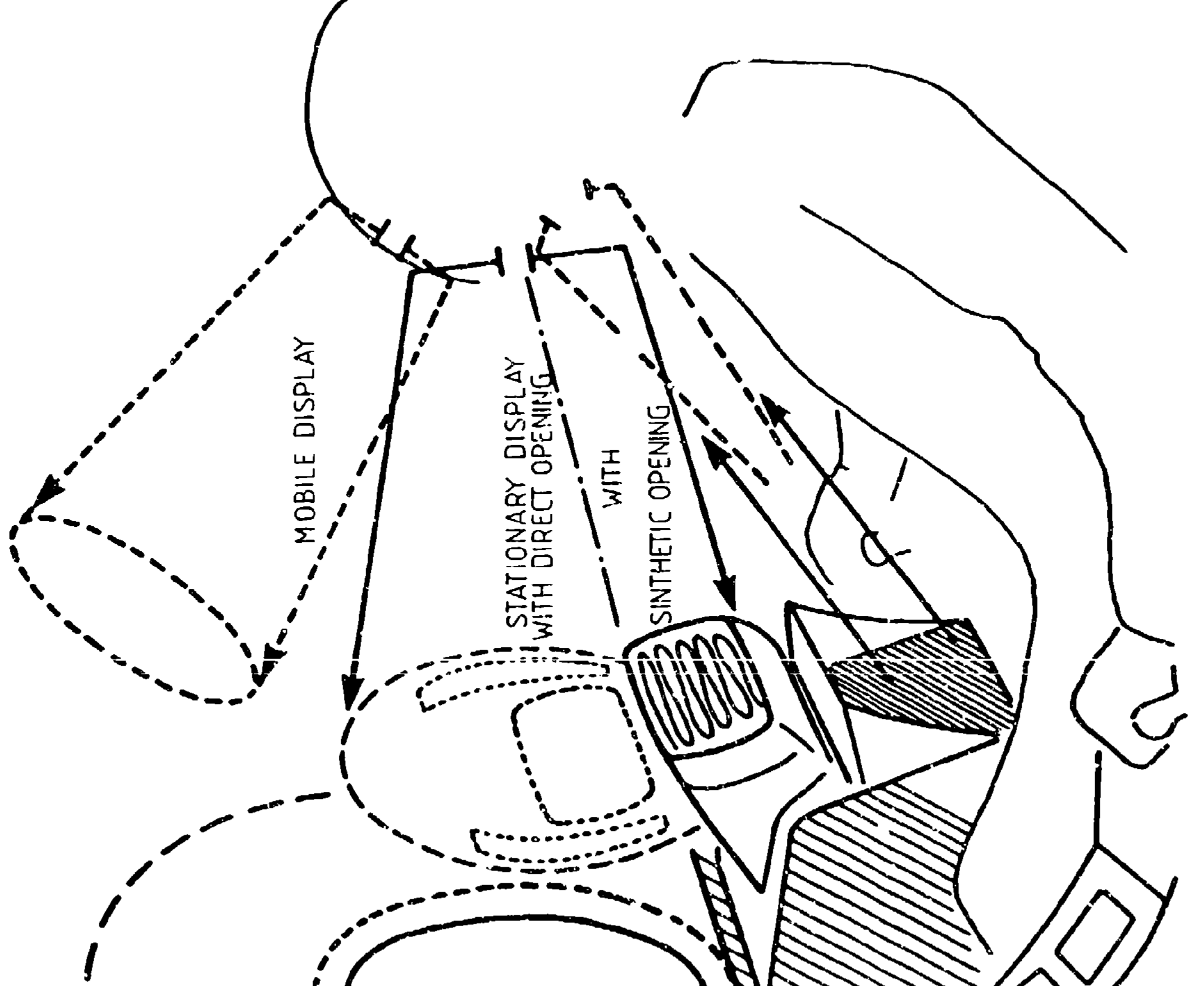
THOMSON-CSF
DIVISION
EQUIPEMENTS AVIONIQUES

IMPLEMENTATION OF THE SECOND GUIDELINE

MEANS FOR THOMSON CSF THE DEVELOPMENT OF NEW COLLIMATED DISPLAY SUBSYSTEMS PROVIDING THE POSSIBILITY FOR THE PILOT IN THE TOUGHEST PHASES OF FLIGHT

" TO KEEP MORE CONTINUOUSLY IN SIGHT THE OUTSIDE SCENE WHILE BEING KEPT INFORMED IN ANY DIRECTION IN THE FIELD OF REGARD "

AN EXAMPLE OF A CONCEPT OF SUCH A SUBSYSTEM IS SHOWN


MOBILE DISPLAY
STATIONARY DISPLAY
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DISPLAY TECHNOLOGY AND THE ROLE OF HUMAN FACTORS

STANLEY N. ROSCOE, JON S. TATRO, EDDIE J. TRUJILLO

Behavioral Engineering Laboratory
New Mexico State University, Las Cruces, New Mexico

As the transition from electromechanical flight instruments to multifunction electronic displays gains momentum, human factors engineers are not well prepared to provide quantitatively specific inputs to the design process. In the 40 years we have been doing flight and simulation experiments, we have not developed a sufficiently comprehensive, empirically based model of pilot performance to assure effective real-world applications. This situation has come about because engineers and behavioral scientists have invested too much of our experimental resources in comparative evaluations of specific devices and not enough in multifactor research. To develop a general predictive model of pilot performance, the effects of and interactions among the many display and control system variables must be assessed (Simon, 1977).

Through the use of the NAVSTAR satellite global positioning system (GPS) in combination with stored maps of large regions of terrain and weather-penetrating imaging sensors, it is now possible to provide pilots with sufficiently precise position information for all-weather instrument flight near the earth's surface. With both terrain and position information, on-board computers can drive navigation displays with dependable flight command information. Such a system has been developed and successfully tested in a UH-1 helicopter at the Yuma Proving Ground. In that test, GPS information was combined with stored terrain profile data to generate desired flight commands. This allowed the pilot to complete several mission scenarios successfully, including terrain following (Woodward and Hoover, 1981).

Such advances in avionics technology have made possible the implementation of several basic display principles that were once impractical. However, the development, evaluation, and deployment of complex systems require a practical, economical, goal-directed approach to system design (Beringer and Roscoe, 1980; Hunt, Howell, and Roscoe, 1972; Roscoe 1982). What direction should the cockpit designer take? What approaches are available to develop, specify, and evaluate new cockpit design principles? A program at New Mexico State University's Behavioral Engineering Laboratory (BEL), under contract with the US Office of Naval Research, has taken a step toward demonstrating a holistic, multifactor experimental strategy for the design and evaluation of display and control systems (Tatro, Corl, and Roscoe, 1983).

CONTEXT

Vertical takeoff and landing (VTOL) aircraft have not reached their operational potential during all-weather instrument flight. A portion of this problem can be attributed to the inherent instability of the VTOLs' current control systems, while the remainder of the problem is due to inadequate flight displays. Both problems are being addressed. A major product of this effort is a horizontal display for vertical and translational control under all-weather operational conditions (Roscoe, Hull, Simon, and Corl, 1981; Roscoe, 1982; Tatro et al., 1983). The display presents HOrizontally and VERtically INteGrated flight control and navigation information (hence, the HOVERING display).

This research effort is concerned with the mutually compatible integration of several individually developed and validated flight display and control design principles. Some of these so-called "principles" have found limited application in operational systems. More often system designers have not availed themselves of features known to improve pilot performance such as reduced orders of control, flight-path prediction, display frequency separation, hybrid compensatory display arrangements, and dynamically adaptive control/display sensitivity logic. Evidently they have perceived such features as too costly and risky with conventional electromechanical display and control technology.

Despite these limitations, throughout the 1970s and early '80s the Office of Naval Research, in anticipation of technological advances, has supported research on display principles, first at the University of Illinois and then at New Mexico State University, to put together all the good old ideas that were once impractical in a systematic way for potential application to helicopters and vectored-thrust VTOL aircraft. Our present problem with VTOL airplanes and helicopters is how to take advantage of their ability to fly like hummingbirds in the execution of low-speed, low-altitude missions totally beyond the capabilities of fixed-wing airplanes, and to do so in bad weather and at night.

The objective of this research is to develop a multiple regression model of helicopter and VTOL pilot performance as a function of a large number of critical real-world variables, including mission relevant task variables, display configuration variables, and display dynamics variables for aircraft having variable control dynamics. The resulting generalizable display and control design principles will provide guidance applicable to aircraft capable of vertical as well as translational flight with a high degree of maneuvering independence in six degrees of

freedom. As technology moves rapidly, so must research if designers are to be guided by a comprehensive, objective data base.

SYSTEM APPROACH

To achieve this goal a system approach is essential. This requires the definition and determination of mission requirements, delineation of system requirements and constraints, development and comparison of potential system configurations, production of an optimum system, and its deployment and evaluation (Hunt et al., 1972). Such a task calls for an experimental strategy and techniques not commonly employed by behavioral scientists (Simon, 1976; Simon and Roscoe, 1981). The development of BEL's MicroGraphic VTOL Simulation Facility and the HOVERING display provides an illustrative example of this approach.

Mission Requirements

In the case of the HOVERING display, mission scenarios require all-weather instrument flight near the earth's surface in VTOL aircraft under zero-visibility conditions. Instrumentation must support a variety of mission scenarios including shipboard landings, nap-of-the-earth flight, and point-to-point hovering and rescue operations over rough seas.

System Requirements and Constraints

The simulation facility had to allow manipulation of vehicle-model characteristics, display parameters, and control system dynamics. The simulation had to enable the investigator to explore the effects of as many potentially important real-world variables as necessary to model pilot performance comprehensively.

Potential Configurations and Prototype System

A conceptual analysis and review of instrument flight problems in piloting VTOL aircraft, including helicopters, preceded the development of a generic VTOL simulation and the initiation of an experimental investigation of critical design variables in forward-looking and downward-looking tactical situation displays (Figure 1). The displays themselves are large, flat plasma screens on which computer-animated contact analog symbology is presented in real time, and in the case of the downward-looking display, altitude and vertical rate information are effectively integrated with horizontal positions and rates to achieve unprecedented accuracy and stability of vertical and transitional flight control.

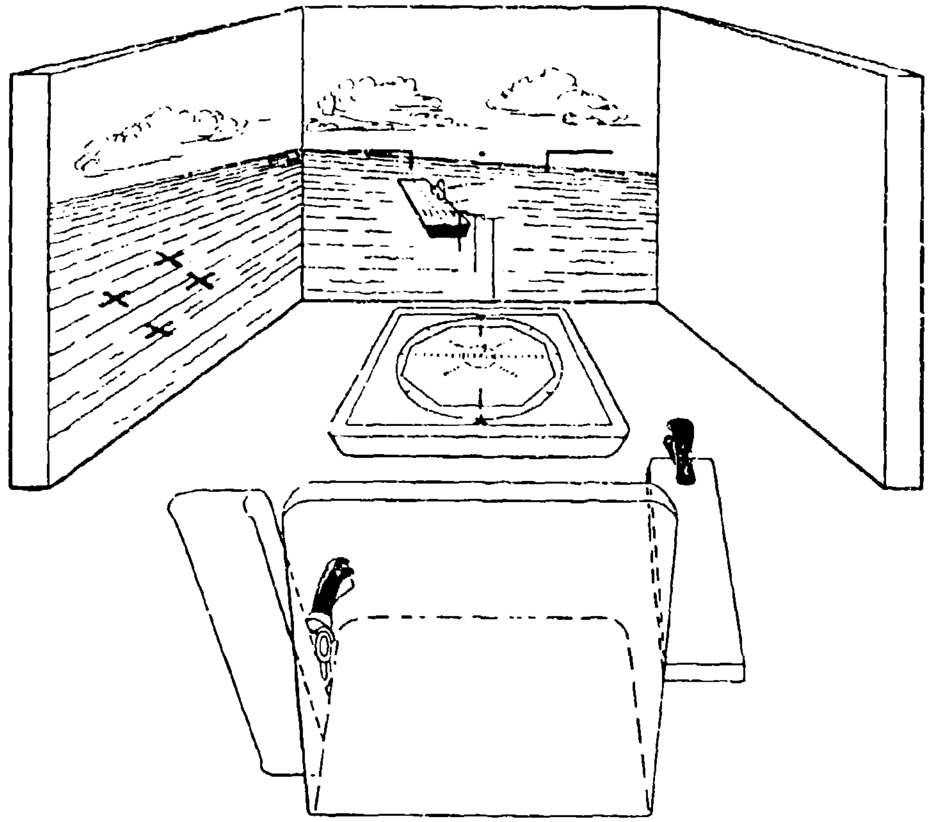

Figure 1. Artist's conception of BEL's MicroGraphic VTOL simulator, including the centrally located HOVERING display (Tatro et al., 1983).

SIMULATION FACILITY

In the BEL MicroGraphic VTOL Simulator, alongcourse and crosscourse translational rates and/or accelerations (depending on the mode in effect) are controlled by a three-axis, spring-centered control stick mounted on the right-hand arm rest (see Figure 1). Alongcourse tracking is controlled by fore and aft stick displacement from a center detent, and crosscourse tracking by left and right stick displacement. Rotating (twisting) the stick about its vertical axis controls the vehicle's yaw (crab) angle relative to the horizontal velocity vector. Vertical flight is regulated by a vertical speed control (VSC) operated by the pilot's left hand. The VSC is spring-centered and viscously damped and is operated by displacing the stick upward to ascend and downward to descend, therby serving as a total-vertical-thrust control.

The vehicle's heading in the horizontal plane is displayed by a rotating compass rose that responds to both crosscourse control inputs and weather-vaning of the vehicle due to the effects of relative wind (Figure 2). A turn-rate index line is shown relative to top-dead-center of the display so that a desired heading can be captured by matching this index with the desired position on the rotating compass rose. Crosscourse and alongcourse rates and/or accelerations are displayed by a position predictor. For vertical flight control, the information provided by the HOVERING display includes a present altitude indicator, desired altitude goal bars, and both desired and actual vertical rate indicators (Figure 3).

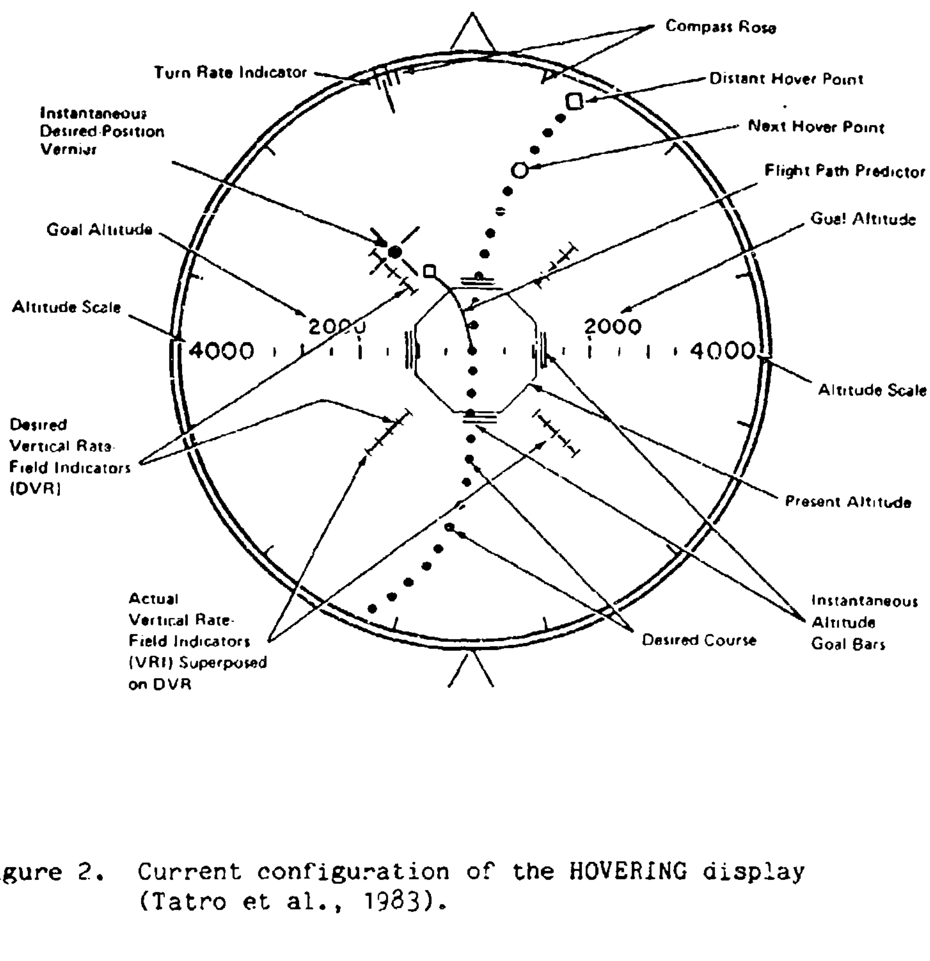

Figure 2. Current configuration of the HOVERING display (Tatro et al., 1983).

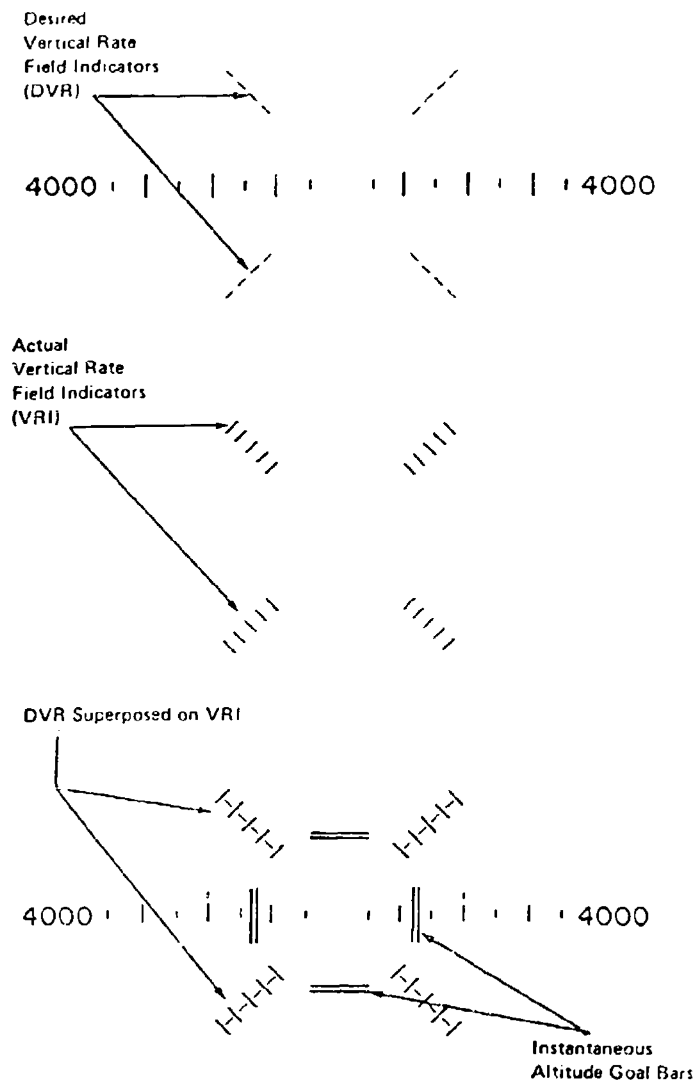

Figure 3. Vertical flight information provided by the HOVERING display.

The present altitude indicator is an octagonal box that dilates as altitude increases and constricts as altitude decreases. Altitude (size of the octagonal box) is read against a fixed scale emanating from the center of the display left and right to the momentary limits of the scale at the display's outer edge. The scale limits automatically change by a ratio of 4 to 1 as the simulated aircraft ascends through the momentary limits and

as it decends within the limits of the next larger scale. Altitude goal bars (AGBs) provide an indication of instantaneous desired altitude. The pilot's task is to keep the octagonal box aligned within the altitude goal bars. The AGBs and the octagonal altimeter move independently; hence, altitude control reduces to a basic pursuit tracking task.

Desired vertical rate-field indicators (DVRs) consist of four sets of bars that flow outward to display desired rate of climb and inward for desired rate of descent. The actual vertical rate indicators (VRIs) consist of four sets of bars superposed on, but perpendicular to the DVRs. The flow of both the desired and actual vertical rate indicators matches that of the octagonal altimeter; outward flow indicates a desired or actual rate of climb, and inward movement indicates desired or actual rate of descent.

A tradeoff exists between the presentation of the "big picture" (for flight planning and navigation) and display magnification with respect to tracking error. An optimum display would somehow present the pilot with the "big picture" while still preserving the necessary sensitivity to allow accurate tracking. One strategy to cope with this tradeoff has been to provide the pilot with a number of selectable display modes, some of which involve altering the screen scale. However, this approach has several drawbacks.

Providing the pilot with selectable screen scales also provides the pilot with increased workload ("What screen scale shall I select?"). It also requires the pilot either to switch back and forth between various scales or select some middle-of-the-road scale that provides a reasonable sense of the "big picture" while allowing acceptable tracking with some compromises in operational capability. Furthermore, selectable display modes involve more switches, and this takes up more and more space in an already overly crowded cockpit (Dasaro and Elliott, 1981).

One alternative to the typical approach might be to provide the "big picture" and also provide a sensitive "vernier deviation indicator" to allow precise tracking (Roscoe, 1968a). A desired course line, next hover point, and distant hover point were included to provide the pilot with the "big picture" (Figure 4). The screen scale for the big picture symbology in this example is equivalent to a 5 nmi (1.5m) radius. The positioning logic for the target cross provides a vernier (magnified) instantaneous desired position indicator. The vernier scale for the target cross represents a radius of 250 feet (76m; this scale can change as a function of mission requirements).

The HOVERING display has several desirable features in

display/control relationships for translational position and rate control. A target or desired flight path is acquired by placing the predictor on the target cross using control inputs from the three-axis side-arm control. Although the display is basically an inside-out presentation, the display has frequency-separation characteristics analogous to those advanced by Roscoe (1968b; Roscoe, Johnson, and Williges, 1980) for aircraft attitude indicators. The predictor functions as an immediate indication of control inputs (high-frequency responses), whereas the closure of error between target and the pilot's point of reference responds more slowly (low-frequency responses). Once a target has been acquired, the predictor should be kept on the target cross as it moves toward the pilot's point of reference.

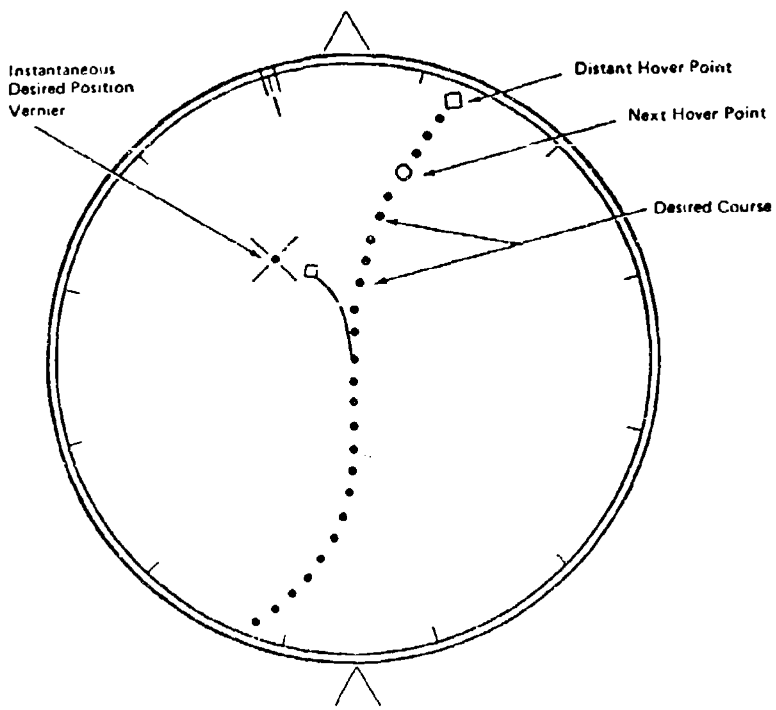

Figure 4. The big picture and the precise tracking symbols in the HOVERING display.

EVALUATION OF THE SYSTEM

A screening experiment was conducted to evaluate the relative effects on pilot performance of eight display, control, and flight task variables. Those variables tested were: tracking mode (TM), flight-path prediction time (PT), flight-path prediction order (PO), magnification factor (MF), control gain (CG), control order (CO), vertical gain reduction logic (GR), and initial position error (IP). Alongcourse, crosscourse, and altitude tracking errors were recorded and analyzed using Yates' algorithm (Simon, 1977). The mean differences for each dependent measure were normalized and plotted on probability paper (Figure 5).

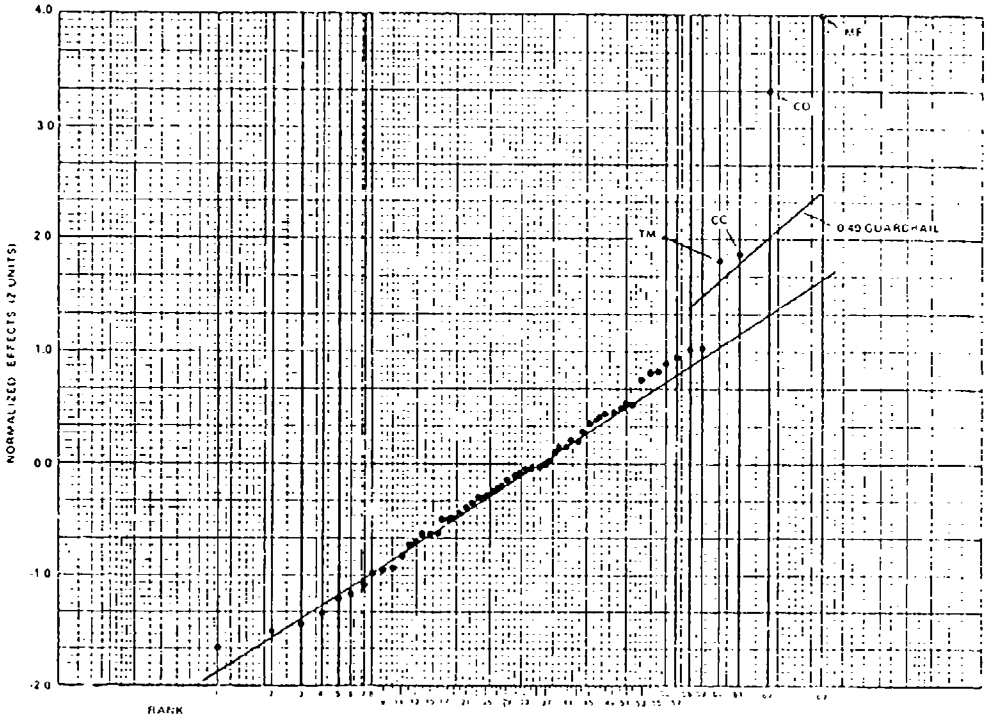

Figure 5. Example of a normal-order plot for alongcourse tracking error (Tatro et al., 1983). The outlying points show which factors have statistically significant and practically important effects.

Those parameters found to be most important are being investigated systematically to optimize the display system across several flight scenarios. Among the parameters found most important are magnification of instantaneous error, control order, tracking mode, control gain, prediction time, and several of their interactions. The outcome of the experiment indicated that the HOVERING display and control system is a positive step toward all-weather flight in VTOL aircraft. This was accomplished by the integration of the basic display principles mentioned previously coupled with a considerable increase in control stabilization.

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PICTORIAL FORMAT PROGRAM: PAST, PRESENT, AND FUTURE

Gretchen D. Lizza
John M. Reising
Flight Dynamics Laboratory
Wright-Patterson Air Force Base, Ohio

Lloyd Hitchcock
Essex Corporation
Warminster, PA

ABSTRACT

The operational use of pictorial graphics in the F-18's stores display sparked discussion between Air Force and Navy crew station design personnel regarding the long-term potential of this type of format for conveying information to the pilot. Based on these discussions, the joint Pictorial Format Program was launched; it consists of three phases: format development, format evaluation (single-seat), and format evaluation (two-seat). The first two phases are now complete, and the third is just beginning. The results, so far, indicate that pictorial formats are, indeed, an efficient means of portraying complex information to the aircrew.

PAST

Introduction

The F-18 crew station is a dramatic break through in cockpit technology. Cathode ray tubes (CRTs), hands-on-throttle-and-stick (HOTAS), and the integrated up front control of the communication, navigation, and identification (CNI) functions are but some of the innovations contained in the F-18. One feature of this cockpit, the graphically depicted stores (weapons) layout, prompted extensive discussions between personnel at the Naval Air Development Center and the Air Force's Flight Dynamics Laboratory. These discussions were the genesis of the Pictorial Format Program (PFP). The primary goal of the program was to evaluate the potential of graphic display formats beyond those used in the F-18. Two key features were incorporated, as mandates, into the approach of the research effort: creativity and advanced technology.

Creativity was emphasized in the work statement by encouraging the maximum use of pictorial graphics in the formats. The contractor was directed to go beyond conventional formats such as those portrayed on an Attitude Director Indicator or on a Horizontal Situation Indicator. In addition, the use of alpha-numerics in the formats was discouraged unless absolutely necessary to portray the information.

The contractor was to assume that such advanced technology as full color, sunlight readable CRTs and readily programmable, raster symbol generators already existed. This assumption may not seem so advanced today since the Boeing 757/767 contain multiple color CRTs, and the F-15 is beginning to incorporate them into its cockpit; however, in 1978, when the work statement was prepared, these technologies were still at the laboratory stage. By exploiting these advancements, new avenues of information presentation, such as

dynamic threat displays, could be explored. Thus, the effort was begun with the hope that the most innovative applications of pictorial formats would evolve.

Pictorial Format Development

In May of 1980, a contract was awarded to McDonnell Aircraft Corporation (MCAIR) to develop the initial pictorial format concepts. This task required production of formats for primary flight, tactical situation, stores management, navigation, engines, and subsystem management. An example of a tactical situation display is shown in Figure 1.

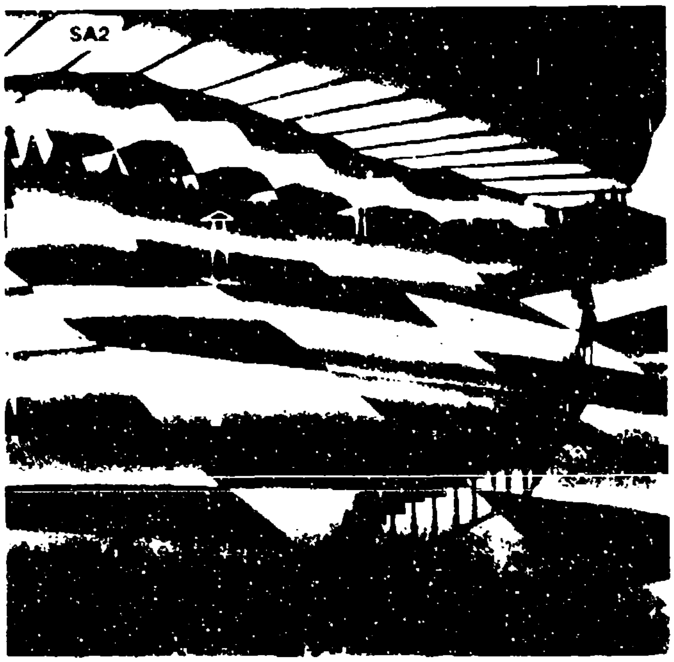

Figure 1. Artist's Conception of a Tactical Situation Display

Each of the above format families was produced in three separate versions: monochrome, color vector graphic (stroke), and color raster. The decision to produce a monochrome version was based on the consideration of retrofitting pictorial formats into current fighter aircraft, none of which contained a color CRT (the Mirage is an exception since it incorporates a penetron, limited-color CRT). An additional reason for the creation of this version of the formats was that comparisons between monochrome and color versions of the formats were planned for the future. The vector graphic version was included because near term color CRT technology projections indicated that, in order to meet the sunlight legibility requirements, stroke writing would have to be utilized. The raster version was based on a longer range projection of the growth of color CRT technology. By including all three versions of the formats, technology insertion could be accomplished whenever the opportunity arose.

The products of this effort (Jauer and Quinn, 1981 a, b; 1982) have been widely distributed and have been presented at various technical meetings

(Reising and Emerson, 1982). Based on the discussions generated by these results, which became rather heated at times, it can be concluded that the first phase of the PFP program achieved its goals. Specifically, the basic concept and use of pictorial graphics, especially those using color, to portray cockpit information was viewed as good. The intense discussions centered almost exclusively around detailed design questions rather than the utility of the pictorial format as a medium of information transfer.

PRESENT

Pictorial Format Evaluation

The second phase in the PFP was to evaluate, through simulation, the concepts developed in the first phase of the program. The overall philosophy of the Pictorial Format Evaluation phase of the program was to use real hardware to create a single-seat cockpit in which the pictorial formats would operate dynamically. The cockpit is located in the simulation facilities of the Boeing Military Airplane Company (BMAC), the winner of the evaluation phase of the program. Although it contains some residual electro-mechanical displays, it is essentially an all electronic cockpit. The key feature of this cockpit is the availability of five CRTs to portray information to the pilot. Figure 2 shows an example of one of the formats displayed in this cockpit.

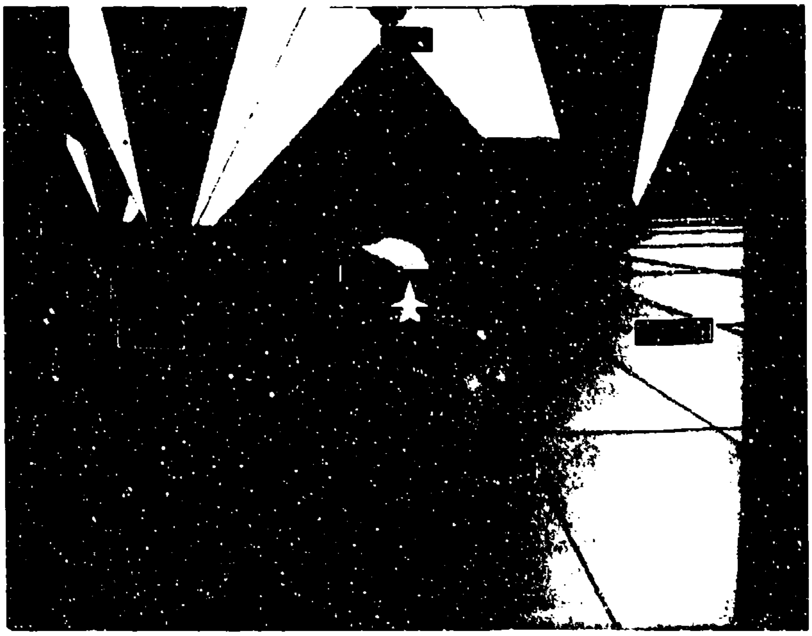

Figure 2. Computer Generated Tactical Situation Display

A total of 30 Air Force and Navy pilots participated in the simulation evaluations. Each pilot flew a composite mission, which included both air-to-air and air-to-ground segments, three times--once with each of three versions of the formats. The pilots had to navigate, fly the aircraft during certain mission phases, set up weapons, handle emergencies, and avoid pop-up threats. The mission was very demanding for a single-seat fighter, but was deliberately designed to be difficult so that any differences in performance while using the three types of formats could be found.

There were a number of important lessons learned from this effort. The first of which is that, if the pictorial formats are carefully designed as usable monochrome displays, the addition of color does not, in many cases, result in a significant performance improvement. Complex, dynamic formats, such as those appearing on a Tactical Situation Display (TSD) prove to be an exception. In this situation, the pilots were able to pick out significantly more pop-up threats with the color display. The second major finding is that the pilots overwhelmingly prefer color displays, and that color raster is preferred over color vector graphic.

In House Research

These Phase II findings are not only true of the intra-pictorial display format evaluation, but are also common to inter-display format research. The pictorial displays developed in Phase I of this effort were evaluated in performance studies conducted at the Flight Dynamics Laboratory where they were compared against alphanumeric displays and voice presentation of the same information. The first of these studies, (Aretz, Reising, Calhoun, and Herron, 1983) compared the effectiveness of alphanumeric, monochrome pictorial formats and color pictorial formats, as well as a combination of alphanumeric and color pictorial formats in portraying weapons status. The objective results indicated that pilots performed equally well with the alphanumeric, color pictorial and the combination of alphanumeric/color pictorial formats, with performance on the black and white pictorial formats being significantly worse than the others. The most significant finding of this experiment was that color pictorial formats can provide an enhanced capability for "situational awareness" especially when combined with alphanumerics. This is because pictures integrate for the pilot several pieces of information into a single chunk, allowing him to retrieve important information at a glance. Again, the value of color pictorial formats for complex displays was validated. But because the data was not strongly conclusive in favor of the pictorial presentation of information, other studies were designed to see how and where these formats could best be used.

A follow-up study focused in on the effectiveness of pictorial presentations during controlled and uncontrolled time durations (Stollings, 1984). The results of this study indicated that color pictorial formats were a superior coding method in situations requiring complex information retrieval during short duration exposures (approximately 100 msec). The color formats were significantly better than both alphanumeric and monochrome pictorial formats.

Another study (Hawkins, Reising, Lizza and Beachy, 1983) compared the use of alphanumeric, pictorial, and voice presentation of emergency notifications and procedures. In this study, pictures did not prove to be better than either text or voice. Even though pilots were throughly briefed on their

meaning, some of the formats apparently required interpretation prior to action, whereas voice and alphanumeric presentation did not. On a closer look, it was noted that some of the formats needed work. For instance, the electrical format was identified as being too cluttered and the hydraulics display format was not as intuitive as initially thought. Although the objective data analysis does not seem to support the investigators strong feelings that pictures are a far better and faster presentation mode, subjective preference supports the continued exploration of color pictorial displays.

Future Direction

Thus far, the pictorial format work has only begun to expose the tip of the iceberg. The results of the Phase II and the in-house evaluation study have provided limited validation for the hypotheses that generated the Pictorial Format research efforts. That is, pictures improve information transfer capability and in turn, will enhance the pilot's operational performance. It is hoped that some of the questions generated by the results to date will be answered by Phase III. In addition, the two-seat fighter has brought new questions to the forefront. Those questions address the need for different types of information displays than have previously been developed. In addition, a whole new problem of crew coordination of tasks and the information required to do those tasks presents itself. In response to these new requirements, Phase III of the Pictorial Format Program is just now beginning. This effort, which is the Multicrew Pictorial Format Phase of the PFP, will include development and evaluation of pictorial format displays which include concepts applicable to the two-seat fighter crew's requirements. The 23 month contract for Phase III has been awarded to the Boeing Military Aircraft Company, Seattle. It began 1 May 1984 and is a multi-sectioned effort.

The overall objective of this third phase of the program is to again assess the usability and acceptability of pictorial formats in conveying system status information in the cockpit, with particular emphasis placed on the second crewmember and crew interaction. The technical approach will be similar to the one used in the Phase II effort; both monochrome and color versions of each format will be evaluated. In Phase III, special emphasis will be placed on responding to the operational needs of the Air Force and Navy aircrews. One of the major intents of the study is to insure aircrew involvement throughout the development and evaluation of the pictorial formats. Aircrew inputs and suggestions will be solicited through both questionnaires and by structured interview. Hopefully, this early and continued interaction with the user, will bring about more realistic formats and facilitate continuity as this technology transitions into the cockpit.

The simulation will utilize both the fore and aft crew stations of the all-electronic cockpit used to initially evaluate the pictorial formats. Mission scenarios will be developed to highlight crew interaction with advanced control and display concepts. The mission will include air-to-ground and air-to-air segments which involve the use of pictorial formats for flight, situation awareness, systems status (i.e., engine, fuels, etc), emergency notification and procedures, and navigation. These displays will be based on the previous work in the Pictorial Format development and the Phase II modifications to those formats. New display formats will be developed based on future mission requirements and the necessary tailoring of existing formats to the two-seat environment. Specifically, these formats will concentrate on target and waypoint previewing, threat response, and stores management.

Several levels of evaluation of the formats will be conducted. The preliminary evaluations will serve as a quality check on the pictorial format development. Design symbology, continuity, coding qualities and other information transfer aspects will be informally evaluated to assess the overall format readability and utility.

The formal evaluation will be based on the performance of sixteen aircrews as they each fly the missions twice--once with monochrome formats in the cockpit and once with the color versions. This section of Phase III will measure their performance on mission-oriented parameters and effectiveness indices. The ease with which the crew can call up the formats will also be examined. The cockpit will allow voice control as well as manual operation of the various switching functions during the missions which will allow an investigation of the relative utility of these combined concepts.

The final portion of Phase III will focus on format revision based on the performance data and subjective evaluation in the testing and data collection sections. A final technical report will be prepared documenting the entire evaluation program including results and recommended format revisions. However, the most important step will be the transition of the evaluated concepts into two-seat Air Force and Navy aircraft such as the F-15 Dual Role Fighter, and the F-14 and A-6 through their update programs.

CONCLUSIONS

The missions of the 1990's will place a tremendous burden on the information processing capabilities of the crew--for both single- and two seat aircraft. It is crucial that information be displayed in a form which is easy and natural for the crew to interpret. As the pictorial format research continues, we learn more about how and where pictures can be used to enhance the aircrew's performance. Their application appears to be most effective in very complex dynamic displays. The results of research performed over the last four years indicate that pictorial formats are an effective means for achieving this goal.

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THE COMMAND FLIGHT PATH DISPLAY - ALL WEATHER, ALL MISSIONS

George W. Hoover
Consultant for Advanced Technology
Systems Associates, Inc. of CA
San Diego, CA 92111

Stephen H. Shelley
Intermetrics, Inc.
Cambridge, MA 02138

Victor Cronauer
Systems Associates, Inc. of CA
Arlington, VA 22212

Stephen M. Filarsky
Naval Air Development Center
Warminster, PA 18974

ABSTRACT

A flight test program was conducted to demonstrate enhancement of pilot performance flying zero-zero conditions using the integrated Command Flight Path Display (CFPD). The CFPD concept requires minimal training for both IFR experienced and limited experienced pilots, compared to the training required when using conventional symbology. This enhancement is accomplished by providing attitude, altitude, direction and speed commands to the pilot in the form of an electronically generated presentation of the real world flight path which should be flown. During the flight test program, the performance of the pilots was measured subjectively through video recording of the Vertical/Head Up Display presentation. Objectively, the performance of the pilots was measured through digital data recordings of their inadvertent diversions from a mean flight path related to the presentation displayed on the Vertical/Head Up Displays.

Program Objectives

Objective - The Naval Air Development Center sponsored the program with the overall objective of proving the validity of the Command Flight Path Display (CFPD) concept during actual flight under simulated zero-zero weather conditions. The Command Flight Path Display concept consists of a totally integrated pictorial presentation of the fundamental information necessary to effectively perform all normal basic flight operations with or without reference to the real visual world.

The specific objectives of the program were:

1. To demonstrate during actual flight that the CFPD was in fact a truly integrated display which provided the pilot with adequate information to execute takeoff, climb, cruise/navigation, ápproach and landing, without reference to conventional parametric displays.

2. To establish that pilot performance with the CFPD was enhanced, demanding minimal concentration on the display, minimizing inadvertent departures, and requiring minimal training time, both initially and for maintaining flight proficiency, as compared to performance utilizing standard symbolic displays.

3. To prove that the electronic system required to generate the CFPD could be achieved by modifying current aircraft display and control systems through the utilization of computer graphics picture processing techniques.

HISTORY

The Command Flight Path Display is the result of approximately 35 years of various research and development programs sponsored by the Navy in an effort to establish an optimal man-machine systems interface.

The concept of a completely integrated pictorial display for aircraft was originally conceived in 1946 as a result of a study performed by the Flight Section, Special Devices Division, Navy Office of Research and Inventions, in conjunction with the University of Illinois.

It should be emphasized that in 1946, and for many years after, there was no known means for displaying the concept.

In 1952 the Office of Naval Research was charged by the Assistant Secretary of the Navy for Air to establish a program with the Bureau of Aeronautics to develop a new concept for aircraft instrumentation. This program was originally a Navy effort conducted jointly by the Office of Naval Research, Air Branch, the Bureau of Aeronautics, Instrument Branch, and the Naval Air Development Center. Later, the Army joined the program because of its interest in improving helicopter instrumentation at which time it was named the Army-Navy Instrumentation Program (ANIP).

The generalized aircraft/man-machine system was identified. Although ANIP sponsored work in each of the system areas, those of the central computer and displays received the most concentrated research. However, the technology was still not available to produce the required display.

Many of the advanced systems now installed in current Navy aircraft came about as a result of the effort of this program which, over a ten-year period, produced the first airborne digital central computer, improved cathode ray tubes, and initiated the practicability of microelectronics. All of these advances, when properly integrated, resulted in the initial demonstration of the concept of a computer graphics generated display which was produced by General Electric under an ANIP contract.

It was not, however, until 1972-73 that computer graphics reached a point where real time, realistic computer generated images utilizing relatively small computers was achieved. This break-through in technology was presented for the first time to the Navy at the First Advanced Aircrew Display Symposium held at the Naval Air Test Center (NATC), April 18-19, 1974.

As a result of the NATC demonstration and interest indicated by DCNO (AIR), Naval Air Systems Command (NAVAIRSYSCOM) through the Naval Air Development Center (NADC) sponsored a study to investigate the feasibility of generating a pictorial display employing real

time computer graphics techniques. The study produced a demonstration by Northrop Aircraft Division in a flight simulator of the original concept of pictorial displays developed under the ANIP program.

Previous research and development efforts had clearly established visual display requirement information and the technical means for generating the displays. The only remaining unknown in proving the concept, currently referred to as the Command Flight Path Display (CFPD), was whether or not improved flight performance could be achieved during actual flight under real or simulated IFR flight conditions.

On 20 April 1982 authorization was given by the Naval Air Systems Command to proceed with Phase I of the CFPD program utilizing the U.S. Air Force NC-131H Total In-Flight Simulator (TIFS) aircraft for installation and flight testing of the CFPD system.

The CFPD Program organization consisted of the following participants:

- Naval Air Systems Command - Program Manager
- Naval Air Development Center - Technical Program Manager
- System Associates, Inc. of CA - Project Manager and System Design Coordinator
- Intermetrics - Software and Data Reduction
- Arvin/Calspan - Installation of the CFPD in the TIFS aircraft and flight test operations.

Display Concept

The Command Flight Path Display Concept is defined as a pictorial presentation of totally integrated real world visual cues which provides the pilot of an aircraft with the following information:

Orientation - Where am I and what am I doing?

Director - What should I do and when?

Quantitative - How am I doing?

All three categories of information are presented relative to the real world vertical plane on a CRT called the Vertical Situation Indicator (VSI), and relative to the real world horizontal plane on a CRT called the Horizontal Situation Indicator (HSI).

The Vertical Situation Display Format should be displayed on a HUD or on a panel mounted CRT VSI, consists of the following three independent elements (Figure 1):

a. A dynamic earth plane or "contact analogue" composed of external reference, linear perspective, texture, size and shape, and motion parallax visual cues, with the capability of angular and linear displacement relative to all three axes.

b. A dynamic flight path composed of the same visual cues as the contact analogue and with the same six degrees of freedom.

c. A command velocity indicator displayed as a three dimensional aircraft located by pilot selection, either to the left, right or center, placed above or below relative to the flight path, and with the capability of changing in size and perspective as the pilot alters his formation position. (During this flight test, the velocity indicator was positioned 150 feet above the Command Flight Path for standardization of test results.)

The Horizontal Situation Display Format is always displayed on the HSI which should be oriented to the horizontal plane. The format consists of the following elements (Figure 2):

a. A topographical map or tactical plot depending upon the type of mission being conducted is provided covering the operational area of the aircraft including terrain characteristics, potential obstacles, navigational aid locations, operational bases, destinations, and targets.

b. A geographical Command Flight Path indicating the proposed or altered flight plan including all segments and way points, the aircraft shadow representing present position relative to the flight path, an indication of where the aircraft should be on the flight path, and an ellipse which indicates range remaining relative to present power, altitude and velocity.

In the test program both displays were included, but emphasis was placed on the Vertical Situation Display with the HSI providing only the geographical Command Flight Path and the aircraft position relative to the Command Position. The program objective was more directed to determining the ability of the pilot to fly the aircraft effectively under IFR conditions, particularly with respect to take-off and landing, and normal flight operations rather than tactical missions. The above in brief, describes the overall basic Command Flight Path concept.

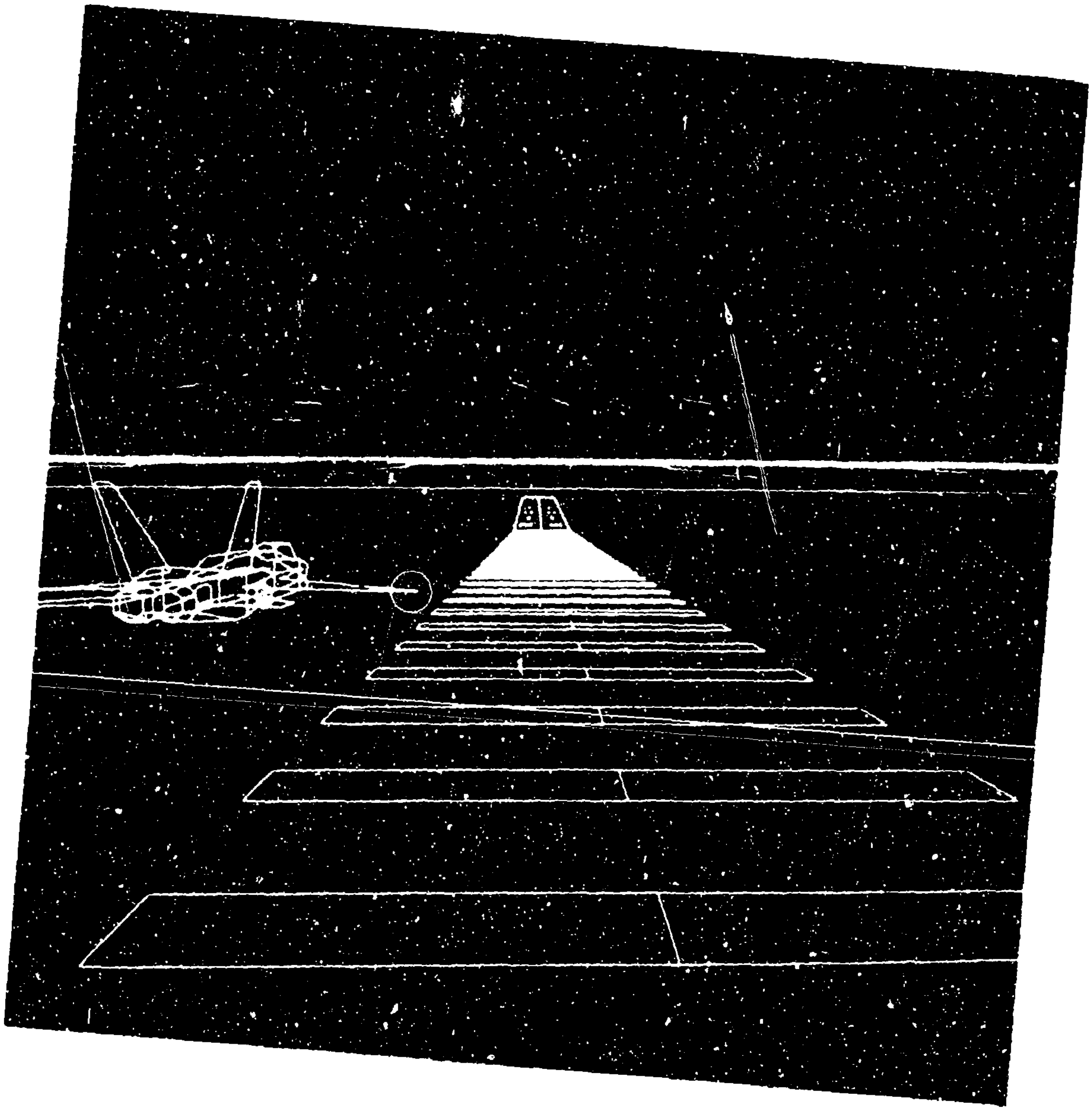

FIGURE 1: CFPD Vertical Situation Display

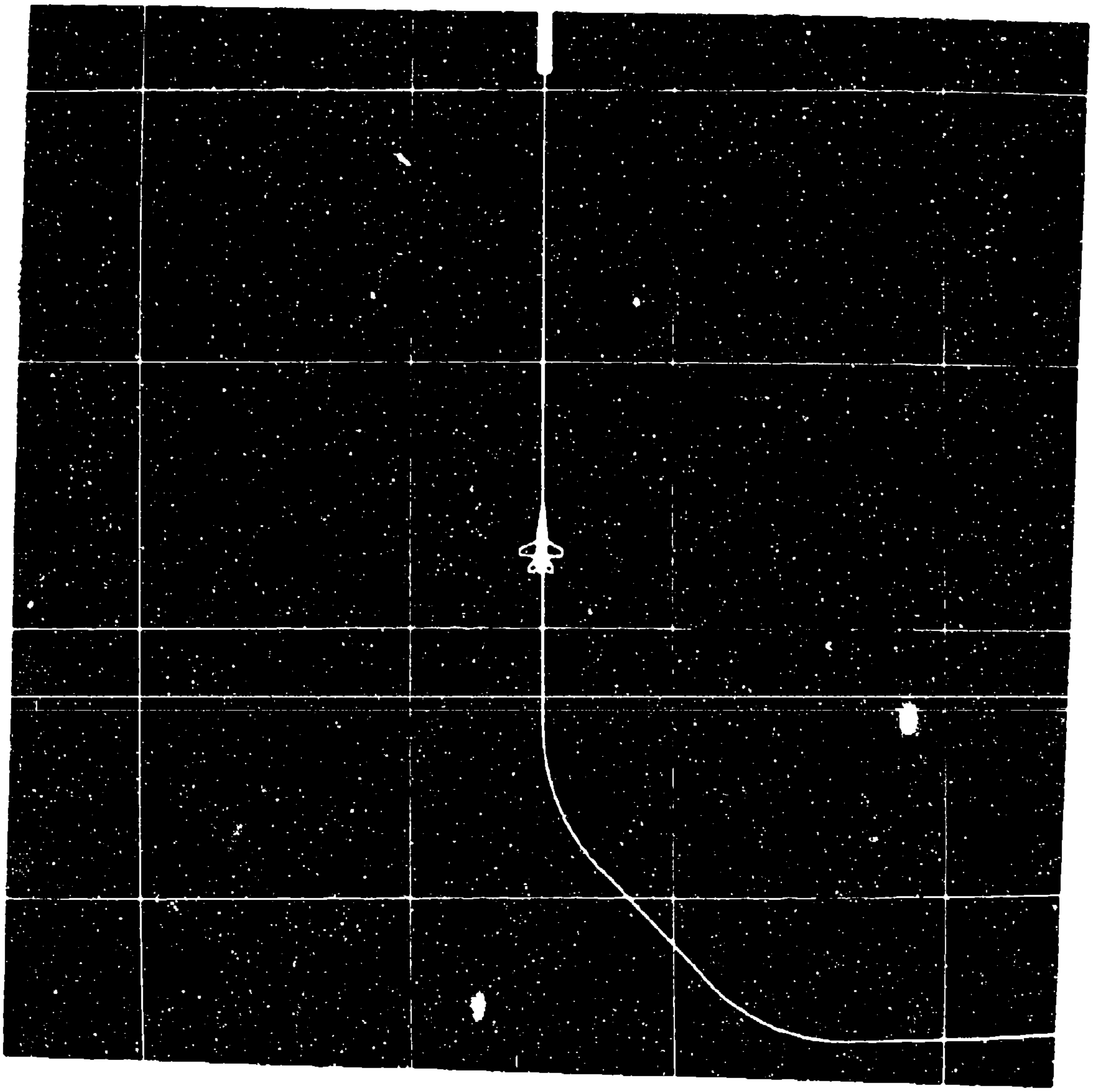

FIGURE 2: CFPD Horizontal Situation Display

CFPD System

In meeting the program objectives of concept demonstration, the CFPD system design utilized a large degree of commercial "off-the-shelf" equipment. In fact, only the inertial navigation platform and diffraction HUD were militarized. This design decision enabled relatively rapid acquisition of the CFPD hardware. In addition, the high-level software development environments available on the commercial equipment provided quick turnaround on system software modifications and supported a high-level of productivity.

The commercial components of the CFPD system were hardened and vibration tested prior to installation in the aircraft. The system was operational for over ninety hours of ground based simulation and over twenty-three hours of flight time. The only hardware malfunction from the start of simulation was in the HUD.

The CFPD system installed in the TIFS aircraft is diagrammed in Figure 3. The key element in the system was the Evans & Sutherland PS-300 graphics system. This component provided all image generation and transformation functions for simultaneous generation of the VSD and HSD formats. The remainder of the system was composed of a DEC PDP-11/44 mini-computer and associated peripherals (digital tape drive, data acquisition subsystem, and hardcopy terminal).

The software component of the CPFD system provided aircraft-related sensor signal processing for navigation, simulation and test support, and data recording, in addition to display generation of both F/A-18 symbology and CFPD formats. This software consisted of approximately 20,000 lines of FORTRAN code and 1,000 lines of PS-300 display program. The PDP-11 software executed using a commercial, real-time operating system (RSX-11S, Version 4.0) and required about 80K bytes of memory.

Flight Test Plan

The procedure for validating the CFPD concept consisted of comparing the flight performance of a number of pilots having different degrees of experience, while flying a specific flight plan, first utilizing a slightly modified current F/A-18 discrete symbol display, followed by flying the same flight plan with the command flight path integrated pictorial display.

The measure of the subject test pilots' performance was based upon the number and magnitude of inadvertent departures from the prescribed flight plan which were recorded relative to the three flight axes plus velocity control, when flying each type of display.

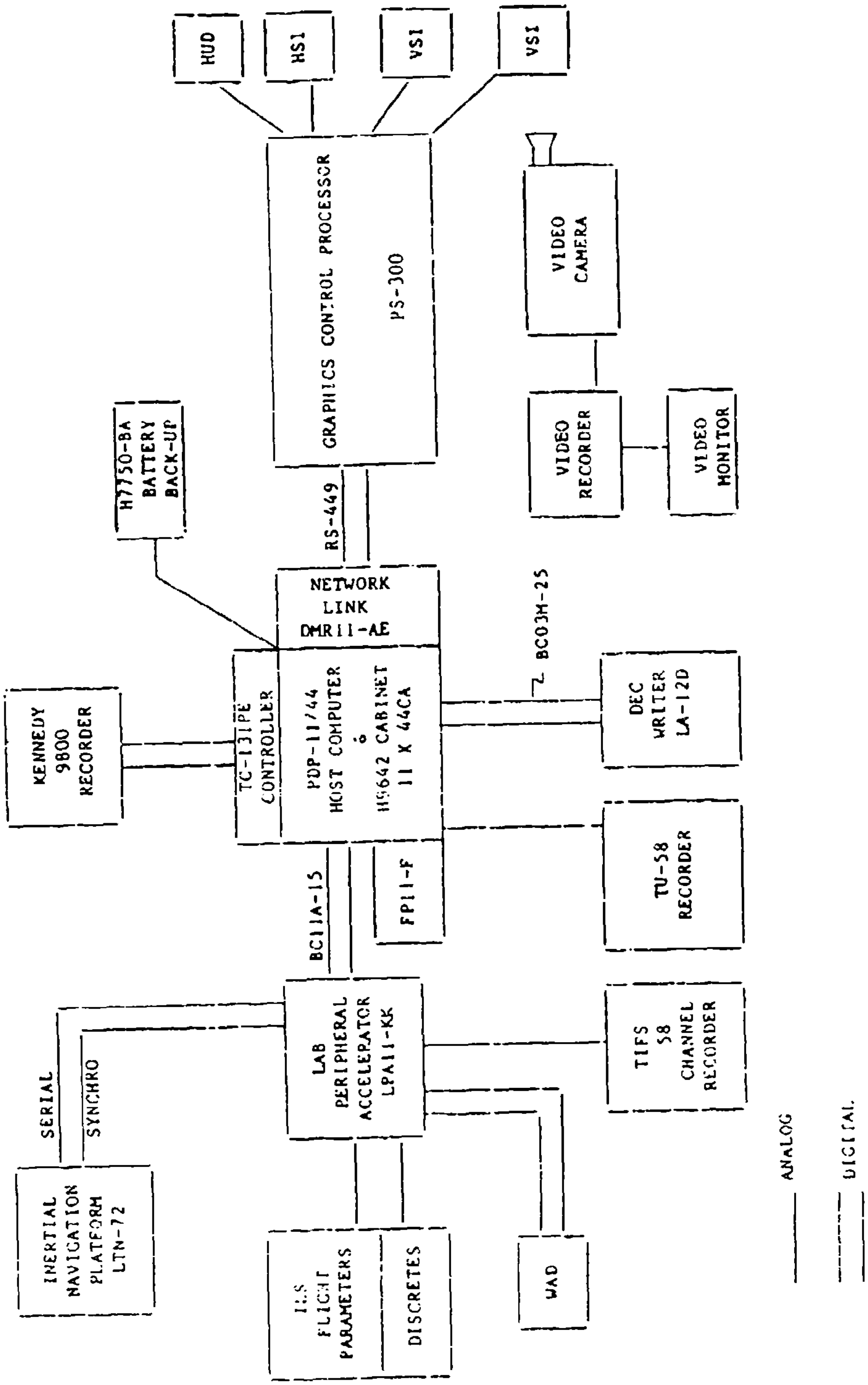

FIGURE 3: CFPD System Diagram

These procedures were performed first with VSI and HSI displays with the test cockpit windows completely covered with translucent material to simulate zero-zero conditions, and then followed by replacing the VSI with the Hughes AIDS HUD and repeating the procedures under acceptable actual minimal weather conditions.

The flight test pattern consisted of a modified instrument flight training pattern composed of a series of interrelated maneuvers and performances basic to normal instrument flight rule (IFR) flight.

The entire prescribed flight pattern was programmed to establish a virtual air space 3000 feet deep, covering approximately 27 square miles with a perimeter of roughly 80 miles. Since the pattern segments and way points were fixed, the coordinates could be oriented relative to any heading and barometric level selected.

In addition to the modified instrument pattern each pilot was required to fly actual ILS-coupled approaches at Niagra Airport utilizing both display formats.

Results

The results of the flight test data were significant. The following table of CFPD flight test statistics summarizes the average lateral and altitude deviations.

CFPD Flight Test Statistics

	PATTERN		APPROACHES	
	CFPD	SYMBOLOGY	CFPD	SYMBOLOGY
Lateral Deviation (ft)				
Max	1081	7017	410	968
Mean	121	1267	89	345
Time Within Lateral Deviations (%)				
<75'	52.1	11.4	71.4	23.4
75-150'	25.9	10.4	13.9	17.3
150-1000'	21.0	42.1	14.1	51.1
>1000'	.9	36.1	.5	8.0

	PATTERN		APPROACHES	
	CFPD	SYMBOLOGY	CFPD	SYMBOLOGY
Altitude Deviation (ft)				
Min	-64	-298	-25	-191
Max	510	502	255	338
Mean	144	51	99	70
Range	574	800	279	529

The analysis of all data generated the following conclusions relative to the objectives of the CFPD program:

a. Objective 1 - Flight test results demonstrated during actual flight that the CFPD was a truly integrated display which provided the pilot with adequate information to execute take-off, climb, cruise/navigation, approach and landing, without reference to conventional parametric displays, or the real world.

b. Objective 2 - Analysis of the operational plots fully establish that pilot performance with the CFPD was enhanced, demanding minimal concentration on the display, minimizing inadvertent departures, and definitely requiring minimal training time (total training time prior to flight was one half hour with the CFPD), both initially and for maintaining flight proficiency, as compared to performance utilizing standard symbolic displays.

c. Objective 3 - The program results proved that the technology required to generate the CFPD was available and could be integrated into current aircraft display and control systems.

In addition to meeting the objectives of the program, considerable knowledge was gained relative to the fundamental concepts of the Command Flight Path Display. The significant conclusions are as follows:

a. The concept of continuous command information is perhaps one of the most significant innovations that the CFPD format provides to man-machine systems displays. By having this information available, the necessity for memorizing each segment of the mission flight plan, or even referring to a navigation chart, is eliminated.

b. Another concept inherent in the CFPD format is the requirement for an integrated display in lieu of combined discrete symbols. Since the word "symbol", by definition, is "something that stands for or represents another thing", it follows that symbols require interpretation, and interpretation, in turn, requires a learning process followed by mental integration.

If, as an alternative, the display consists of an integration of real world visual cues, no learning process or interpretation should be required and the information present in the display would be acquired through differentation.

Examination of the performance plots of each evaluation pilot very definitely established four significant differences between the F-18 type symbology and the CFPD, which substantially influenced the obvious differences in performance.

1. Essentially no learning process or interpretation was required by the evaluation pilots when flying the CFPD. Each pilot saw the CFPD format for the first time on the evening before his evaluation flight and flew the format in the ground simulator for only one half hour prior to his first actual flight.

2. The second important difference between the symbolic format and the CFPD relates to disorientation. Several of the evaluation pilots indicated experiencing vertigo during some of the flight maneuvers while flying the symbology. None of the pilots experienced any form of disorientation that affected his operation of the aircraft while flying the Command Flight Path Display.

3. The concept of utilizing the VSI and the HSI with the CFPD format provides an excellent indication of the wind effect relative to take-off and climb, cruise, and approach and landing. The immediate indication of a change in wind direction becomes evident when corrections in heading are required to stay on the centerline of the flight path on the VSI.

   In addition to the above, turbulence effects were no different visually in the CFPD than they would be when flying VFR.

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SENSOR-COUPLED VISION SYSTEMS

Tom Stinnett, Human-Systems Laboratory

Westinghouse Defense and Electronics Center (D&EC)
Baltimore, Maryland

Presented at The Advanced Aircrew Display Symposium
Naval Air Test Center, Patuxent River, MD.

The activities described in this paper were jointly conducted by the Human-Systems Lab, Display Technology Group, and Flight Development Lab of the D&EC and the Human-Sciences Lab of the Westinghouse R&D Center, Pittsburgh, PA.

ABSTRACT

A low-level flight test was conducted by Westinghouse in the mountains of Central Pennsylvania to determine the ability of a pilot to fly during VFR conditions while viewing the terrain through eyeglasses with different fields-of-view. The conclusions indicated that a head-mounted display and electro-optical sensors providing a composite wide and narrow field-of-view are esssential.

The results of this flight test has led Westinghouse to pursue R&D activities in the areas of developing such a capability and the use of oculometers and eye-tracking processing to control sensor look-angles and computer-CRT cursors.

1 INTRODUCTION

What is one of the more serious deficiencies of American military systems?

The disparity between equipment and human performance capabilities.

Technical advances in micro-electronic technology have enabled the performance of electronic components to be dramatically increased, while at the same time increasing their performance. The same is true for servo-mechanisms, sensors, and other electromechanical devices. Unfortunately, the complexity of machine operation and maintenance has increased just as dramatically. This trend can be expected to continue into the foreseeable future as shown in Figure 1-1.

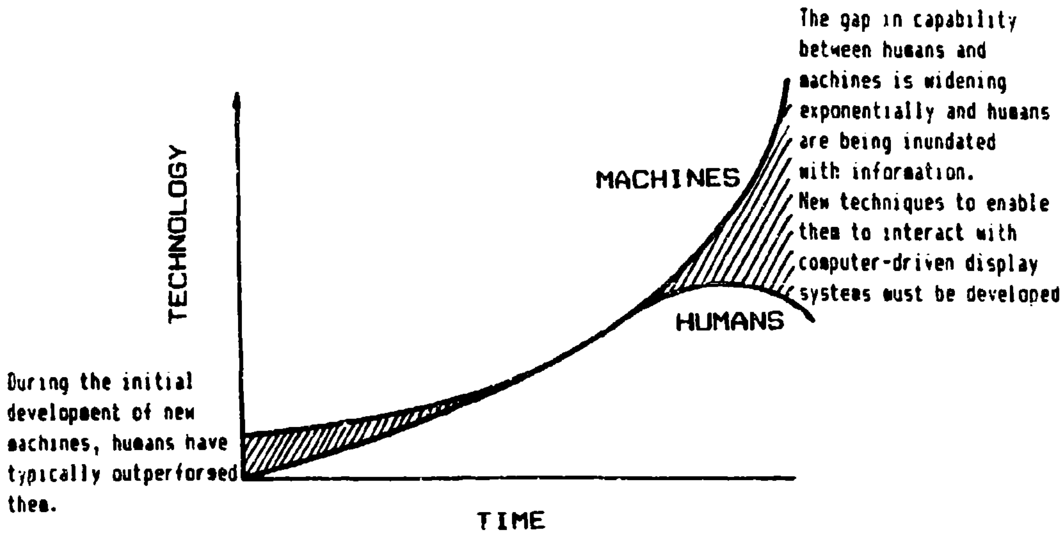

Figure 1-1 Human Input Versus Computer Processing Capability

The proliferation of computer-aided systems has caused human decision-making to increase rather than to decrease which is counter to normal expectations. Humans have been able to continue to function despite increased workload and decision-making because of their innate capacity for adapting to dynamic situational demands. Humans are psychologically and physiologically very flexible in adapting to a wide range of environmental working conditions and performance requirements. Nevertheless, many operators have reached a level of workload saturation largely because of the inefficient design of human-systems interfaces.

As system capability increases, the number of system functions and mission modes also tends to increase. This is evidenced in the increasing emphasis being placed upon robotics and artificial intelligence to reduce the burden on human operators and to improve system performance, as well as to reduce expensive labor-intensive production and manufacturing lines. Rather than working with hard materials and components, humans are working with information.

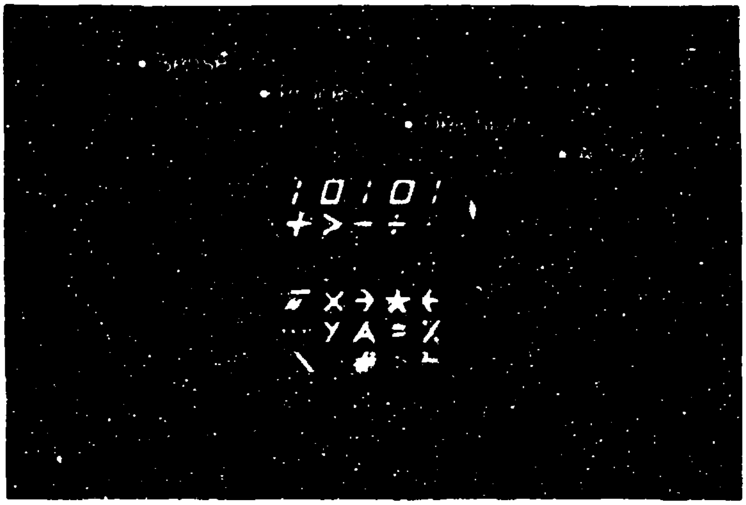

Figure 1-2 Mental Workload Saturation

The premise that human interaction is not necessary nor even desireable is a faulty one since even so-called fully automatic systems require some level of human interaction, if not on a continuous basis, at least on a monitoring and override basis. Maintenance and repair also requires human intervention and interaction. This is also true for computer systems employing artificial intelligence as a means of emulating the human thought process. Human interaction is required in some form and at some level-of-effort for computer input preparation and insertion, system monitoring, and output application. Machines are tools to provide artificial extensions of human physical and mental functions. Humans are not tools of machines. At least, they shouldn't be.

Research and development tasks are being performed by human-systems and display engineering specialists at the Westinghouse Defense and Electronics Center, Baltimore, and the Research and Development Laboratories, Pittsburgh, to conceive and develop innovative, more efficient display and

control techniques related to multisensor integration, artificial intelligence, and computer-aided crew stations. The objective is to reduce the amount of usage required of keyboards, handcontroller devices, and discrete switches to control the movement of CRT cursors for purposes of target and data designation and for the control of the look-angle of electro-optical sensor systems. In addition, advanced sensor/display systems techniques to emulate and interact with human psycho-physiological systems are being researched and developed.

2 FIELD-OF-VIEW FLIGHT TEST EVALUATION

The interest in developing techniques to more directiv couple humans with machines was sparked by the realization of the need to provide a 24-hour day/night, all-weather, low-altitude weapons delivery capability. The ability to successfully perform this mission to provide close-air support and battlefield interdiction with an acceptable probability of success and survival is highly questionable. The same is true to penetrate across the FLOT into hostile territory for deep strike and interdiction missions. If the pilot's view of the world is dependent upon artificial sensor and display information, he is severely constrained as to visual aperture (field-of-view). Therefore it was desireable to determine the effects of sensor/display aperture size upon the pilot's ability to fly a TF/TA profile (below 500 feet) at speeds consistent with the close-air-support and battlefield interdiction missions (300 knots). Since the major obstacle to providing such a capability is the disparity between electro-optical sensors and the human visual system i.e., between field-of-view and resolution, a series of flight tests was conducted to evaluate the effects of viewing the real-world through different size fields-of-view.

Many conclusions were reached during these tests among which were the following. It was very apparent that the ability of the pilot to move his head and eyes on a "swivel neck" is essential for flying low altitude TF/TA profiles through mountainous, hilly terrain such as that in Central Pennsylvania. Terrain in Central Europe such as in the proximity of the Fulda Gap is quite similar. To fly TF/TA during night and adverse weather conditions, it was concluded that an electro-optical image must have the following attributes; be head mounted, provide binocular vision if possible, and provide a visual field-of-view of 40-degrees lateral by 30-degrees vertical. Peripheral vision and visual acuity were highly significant in providing TF/TA flight cues to the pilot. Although the area of human visual perception of ambiguous, paradoxical, and uncertain shapes was not addressed, this is certainly an important factor for low-altitude, high-speed navigatioon and weapons delivery. It is certainly an area of research deserving of detailed study. It would also be very desireable to find some way to extract quantitative measures of pilot performance as a function of limited fields-of-view. How to accomplish this remains undetermined.

Table 2-1 provides a summmation of conditions, the visual field-of-view sizes evaluated, and key observations resulting from these flight tests.

Table 2-1 Summary of Sensor-Coupled Vision Flight Test

CONDITIONS	FIELD-OF-VIEWS
16 June, 1981	Binocular:
Visual Route 1757	48X36-degree Agile
Sabreliner 40	40X30-degree Agile
2 Test Pilots	30X18-degree Fixed, Snap-Look, Agile
10 Passes (5 each)	20X15-degree Fixed, Snap-Look, Agile
11:00 A.M.	Monocular:
	40X30-degree Agile
10 Mile Visibility	
300KTAS	

CONCLUSIONS

For Low Altitude Terrain Avoidance:
Head Agility - Required
FOV >=40-degree - Desired
30-degree - Possible
20-degree - Too Restrictive
Binocular - Desired

The flight test was conducted as simply as possible to reduce test variables to a minimum. It was also decided to forgo sophisticated data recording and analysis techniques and to restrain the tests towards acquiring empirical knowledge rather than quantitative analytical results. The test procedures were structured to obtain pilot subjective opinion of the ability to fly the mission profile while viewing the real-world scene through various fields-of-view. The different fields-of-view were provided by modifying safety eyeglases to provide different viewing aperatures as shown in figure 2-1. Eyeglasses were chosen since the pilots were viewing the real-world through the windscreen and it was much more accurate to control the geometry of the aperature sizes relative to the facial physiological characteristics of each pilot. The intent was to locate the visual aperture for each eye centered to the pupil of each eyeball. This eliminated the possibility of inadvertently extending the visual angle for each eye by viewing out of the aperture for the other eye.

Figure 2-1 Eyeglass Apertures

The flight conditions were:
1) Aircraft: Westinghouse Sabreliner 40
2) Flight Test Personnel: Pilots- J.F. Fendley (Pilot 1), D.Z. Skalla (Pilot 2), Human Factors Observer, T.A. Stinnett.
3) Date: June 16,1981.
4) Time of Day: 9:50-11:10.
5) Weather: Clear visibility 10 nmi, slight haze, scattered cumulus at 5000 AGL.
6) Speed: 300 KTAS.
7) Route: Visual Route VR 1757, segment C 40-degrees, 41-minutes north/77-degrees, 58-minutes west to segment D 40-degrees, 47-minutes north/78-degrees, 15-minutes west.

This route segment is located in Central Pennsyvania and runs in a west/northwest direction starting at a point approximately 9 statute miles southwest of State College,

Pennsylvania. The terrain in this area is characterized by low mountains and rolling hills. Ridge lines tend to run orthogonal to the flight path making it possible to exploit the terrain for TF/TA manuevers. Mountain elevations above pass elevations are typically 500-700 feet with ridge lines spaced approximately 7000 feet peak-to-peak. Pass widths are typically 1000 feet wide with the narrowest flown being approximately 220 feet wide. Passes through ridge lines are not coincident making it necessary to perform up to 2.5 to 3g maneuvers at speeds of 300 KTAS. The terrain foliage generic to this region ranges from complete cover by deciduous and pine trees to open pasture farm land. The flight path overflies a number of cultural features and targets of interest including paved roads, dirt trails, railroads, streams, ponds, farms, high tension lines, an automobile junkyard which resembles a motor pool, and coal strip mining areas. Figure 2-2 shows a contour map of this region with a typical segment of Low-Level Military Training Route 1557 flown for this flight test delineated by a solid black line. The numerals 1,2,3 spaced along the flight path are correlation points plotted between the aircraft location with specific image film frames.

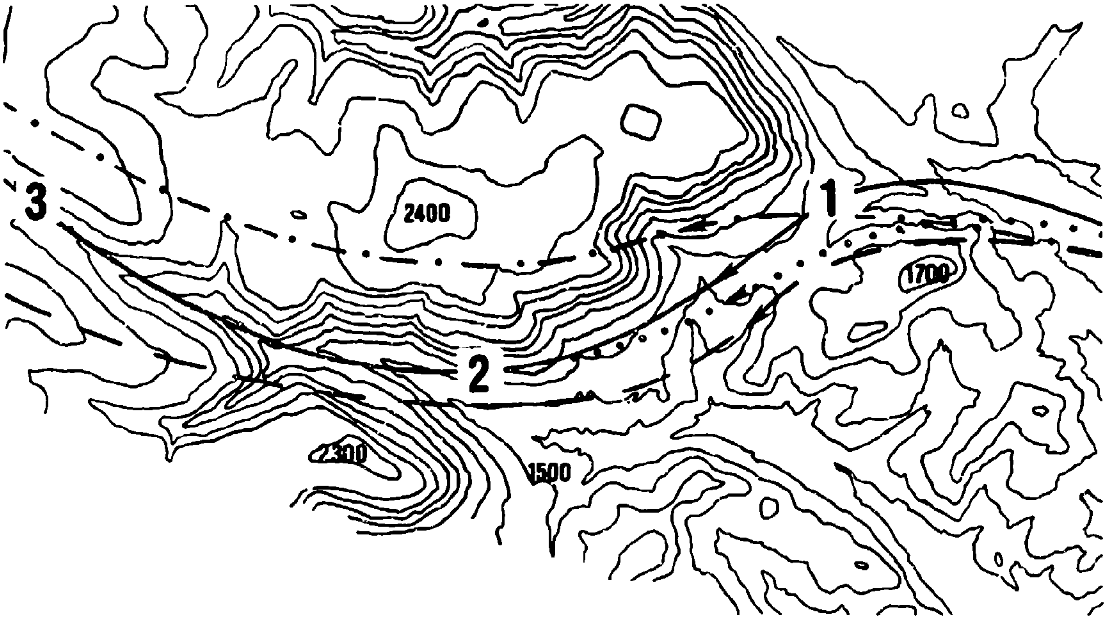

Figure 2-2 Contour Map Plot of SCVS Flight Test - Visual Route VR 1757, Central Pennsylvania

Five different sizes of eyeglass field-of-view aperatures were chosen for evaluation. Two of the sizes were current and LANTIRN head-up display (HUD) fields-of-view and the remaining three were selected because they represented the state-of-the-art of EO sensor technology. Table 2-2 specifies the aperture sizes.

Table 2-2 Fields-of-View Evaluated in SCVS Flight Test

Horizontal Field-of-View	Vertical Field-of-View	Diagonal Field-of-View	System
48-degrees	36-degrees	60-degrees (3x4 ratio)	SCVS Future (Agile)
40-degrees	30-degrees	50-degrees (3x4 ratio)	SCVS Baseline (Agile)
30-degrees	18-degrees	35-degrees	LANTIRN Holographic (Fixed/Snap-Look & Agile)
20-degrees	15-degrees	25-degrees	LANTIRN Standard Optics (Fixed/Snap-Look & Agile)
40-degrees	30-degrees	50-degrees (3x4 ratio)	SCVS Future (Agile Monocular)

The middle size FOV of 40-degrees horizontal by 30-degrees vertical is considered to be the most realistic maximum aperature size that can be achieved with current EO technology. Because time, money, and FAA regulations precluded any attempt to emulate a HUD field-of-view by more elaborate aperture apparatus, it was not possible to exactly represent a HUD field-of-view. When flying a segment evaluating one of the two HUD fields-of-view, the pilots attempted as best they could to fixate their heads forward and to resist moving their heads to extend the visual field-of-regard. During the four runs to evaluate HUD fields-of-view, they also exercised full agility of head movement during a portion of the run as they did with the SCVS fields-of-view to enable a comparison to be made of the 20-and 30-degree fields-of-view with the 40 and 48-degree fields-of-view. The two larger eyeglass apertures of 40-and 48-degrees were considered to represent a helmet mounted SCVS display and the pilots were unrestrained in their head movements at all times. The question of monocular versus binocular vision was carefully considered prior to constructing the eyeglass apertures and it was decided to provide binocular apertures with the ability to block the

left aperture to monocular vision only. The state-of-the-art of helmet-mounted display technology has prohibited the provision of binocular vision capability and this limitation is considered to be somewhat controversial as to the effects on pilot psycho-physiological reaction.

For clarification, it is necessary to understand that the SCVS flight test was conducted viewing the real-world scene with binocular vision. However for an actual SCVS system, the pilot would be viewing an electro-optical display image with binocular vision. When viewing the real-world, each eye sees the scene from a slightly different angle as a function of range to the point focussed upon. When viewing an electro-optical image, each eye will see identical scenes independent of range to a point of focus and it is not known if this is significant. It is obvious that to provide binocular vision for a helmet-mounted display, the complexity of the optical/display mechanism is greatly increased as compared to that required for a monocular system. For example, a binocular system requires very precise adjustments to ensure that each exit pupil is exactly centered over each eye to ensure that only a single image is perceived. Singleness of object vision is dependent upon the light from a single object impinging upon the retinas of both eyes at identical points. If differences of impingement exist, double vision will occur if the disparity is large enough, or if the disparity is not significant, the object will appear as a single object but at a range further or nearer than for a fixated object. Whether or not this complexity is warranted is unknown at this time. To obtain some feel for pilot reaction, several passes through the route were made using monocular vision by blocking out the left aperture. The tradeoff between binocular and monocular vision will require much more study and research before any intelligent decision can be reached. However pilot observations were that the use of both eyes was superior to monocular vision.

Both pilots had previously flown VR 1757 making it unnecessary to fly any familiarization passes. The basic flight procedure was for one pilot to fly east to west over the course segment wearing one of the eyeglasses and the other to fly the reverse direction wearing the same eyeglasses. Both pilots tested all apertures giving a total of ten runs over the course. The sequence of test for the eyeglass apertures is shown in table 2-3.

Table 2-3 Sequence of Test

Horizontal Aperture	Remarks
48-degree binocular	Pilot allowed to move head freely.
40-degree binocular	Pilot allowed to move head freely.
30-degree binocular	Pilot instructed not to rotate head laterally if possible except for snap-look.
20-degree binocular	Pilot instructed not to rotate head laterally if possible except for snap-look.
40-degree monocular	Pilot allowed to move head freely.

This sequence was chosen to provide as much terrain familiarization as possible to the pilots working from the wider to the narrower apertures since it was reasonable to assume that the narrower apertures would be progressively more difficult to fly with. The test pilots were asked to restrict the movement of their heads as little as possible from a position looking dead-ahead when wearing the 30 and 20 degree aperture eyeglasses. The purpose of this restriction was to replicate as closely as possible the viewing of an electro-optical image through a head-up display fixed to the glare shield. They were permitted to rotate their heads just prior to executing a turn to achieve a "snap-look" effect. For all other aperture sizes, the test pilots were asked to move their heads as naturally as they desired to replicate a helmet-mounted display. The 40-degree aperture size was flown a second time with the left eye aperture occluded to provide monocular vision only. This was done to enable a subjective opinion to be expressed by the pilots of the relative merits of binocular versus monocular viewing. The pilots were asked to fly a TF/TA profile as low as possible commensurate with the FAA regulations governing visual route VR 1757.

Data recording was limited to the voice recording of subjective opinions and comments made by the pilots during and after each pass. The purpose was to capture their spontaneous impressions. A debriefing session was also conducted after returning to the Westinghouse Defense and Electronics Center Flight Test Facility. A second debriefing was conducted with Westinghouse management and engineering personnel at a later date.

Photographic recording during the flight test was made by the human factors flight engineer using a Canon AE1 35mm camera loaded with Kodak Kodacolor 400 film. Movie camera film recording of similar flights through the route were made on September 17,1981, after it was decided to continue to pursue research and development related to sensor-coupled

vision systems. For these scene recording flights, a 16mm movie camera providing an 85-degree field-of-view was hard-mounted into the nose of the Westinghouse Sabreliner to provide the widest possible field-of-view. This camera installation required the removal of the weather radar antenna, the design and construction of a camera hard-mount structure, and modification of a radome to provide a window for the camera lens. In addition a 35 mm movie camera was mounted above the pilot's seat at a position approximating the eye location by suspending it from the ceiling of the cockpit by "bungee cords". The camera was hand-held so that it could be retained at a HUD positon or rotated freely to follow the pilot's visual gaze-angle to emulate a helmet-mounted display.

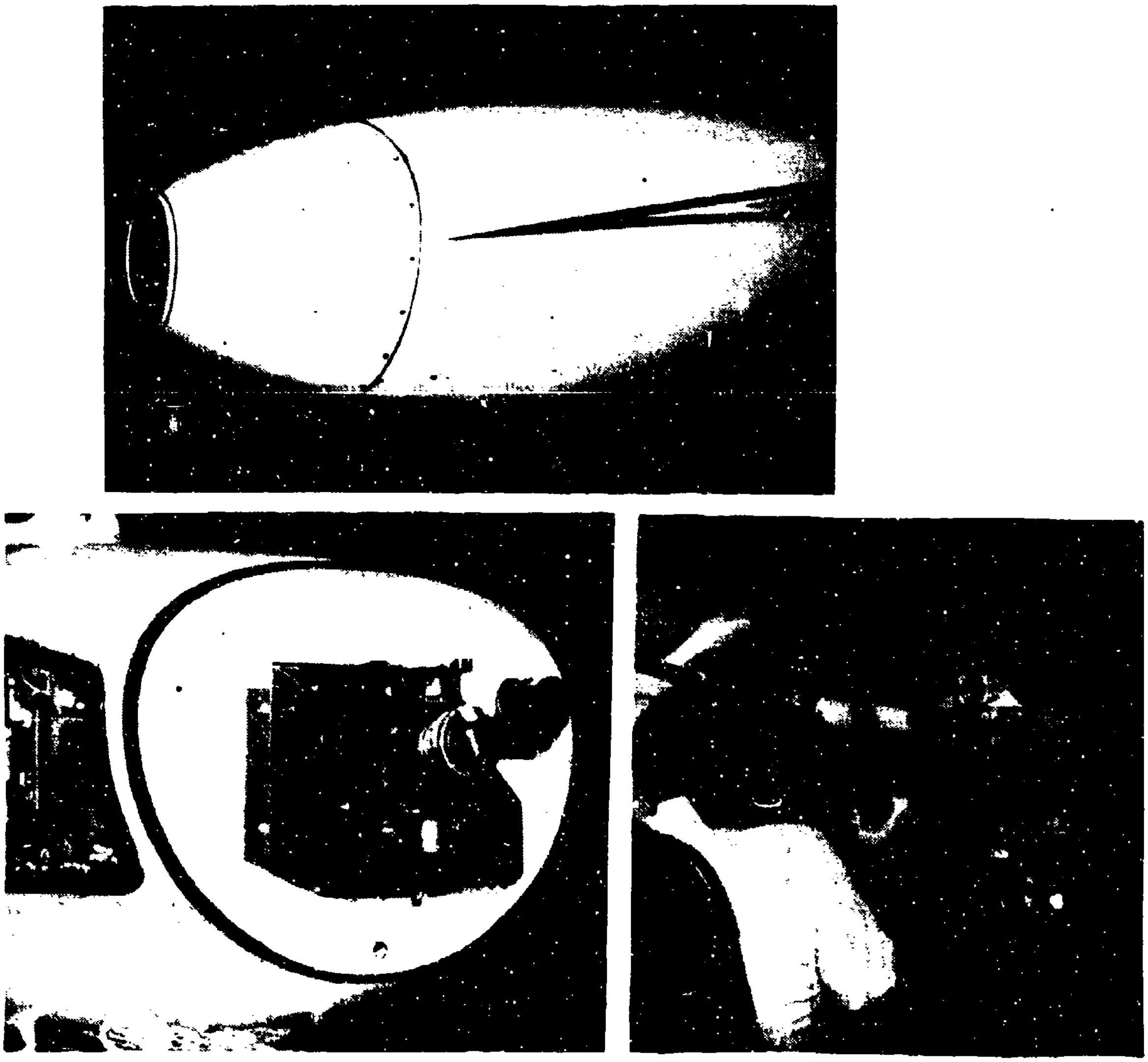

Figure 2-3 Sabreliner Camera Installation.

A total of six passes was made through the route and both fixed and free-rotating camera movements were conducted. The recorded film was processed and has been used to provide imagery for subsequent human factors research related to sensor-coupled vision systems. Figure 2-4 shows examples of 35mm film recorded scenes.

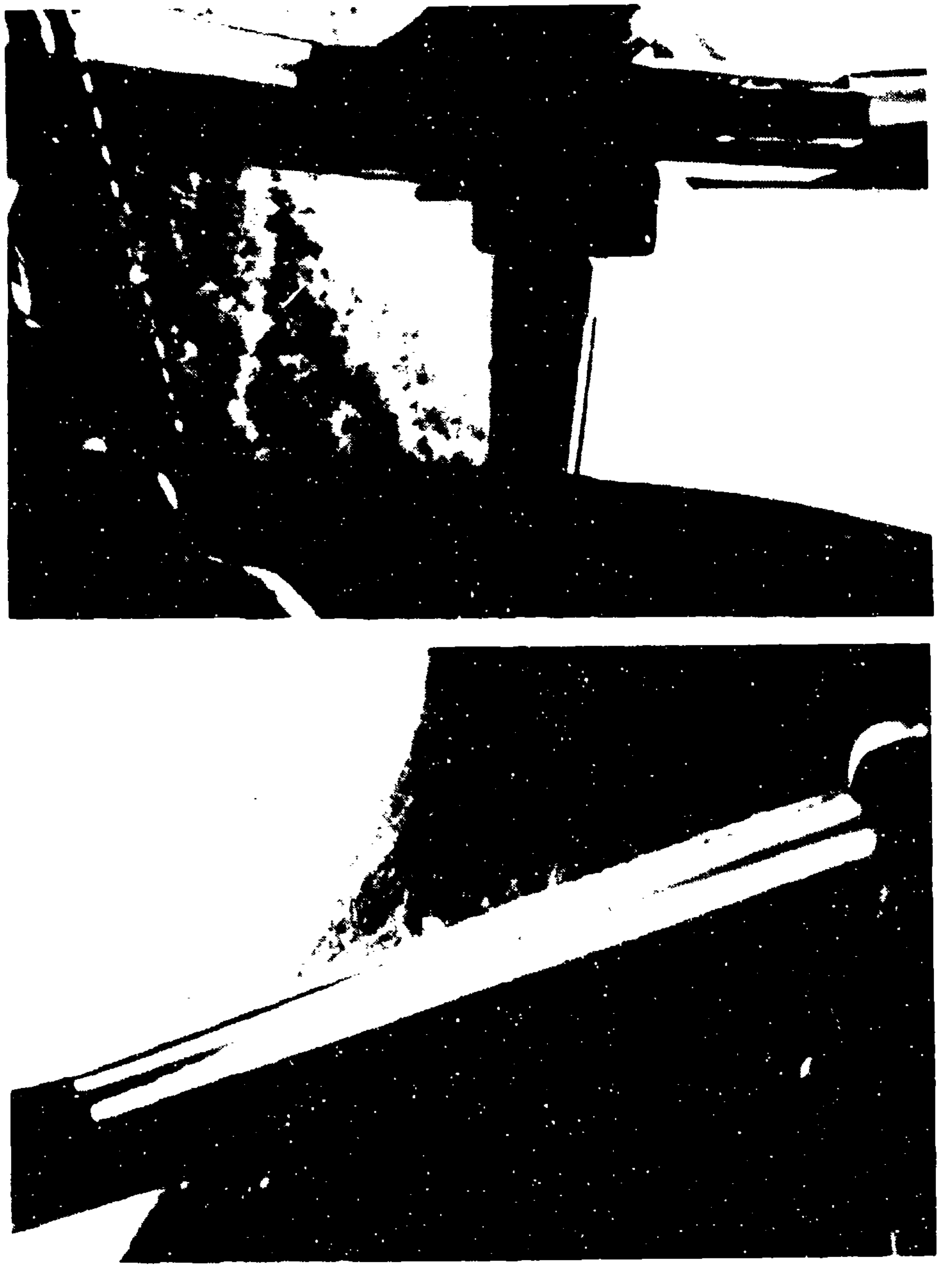

Figure 2-4 Examples of 35mm Film recorded scenes.

The human factors flight engineer also made a voice recording calling out radar altitude and the initiation and termination of each maneuver during the flights. The purpose was to obtain a timeline and profile for plotting on a 1:24000 scale U.S. Geological Survev map. This also enabled photographed areas to be correlated with the map.

The results of this flight test were subjective with no quantitative data recorded, therefore caution is advised in attempting to extract specific conclusions from pilot observations and opinions. Key observations are summarized as follows:

* Peripheral vision is very critical to the pilot as a means of discerning range, altitude, speed, and anticipation of the terrain characteristics in front of the aircraft into which he wants to maneuver.

* Both pilots expressed astonishment at how much they relied upon peripheral vision under normal visual conditions to provide depth perception cues. They were nott aware of this dependency until their peripheral field-of-view was reduced.

* Monocular viewing as compared to binocular viewing was much more difficult. Depth perception was completely lost making it difficult to estimate the distance to the next ridge-line and altitude was very difficult to estimate. Monocular viewing caused both pilots to underestimate their altitude by half. Both pilots exitited a reluctance to push over after crossing a ridge-line because of the altitude perception problem. It was also more difficult for the pilots to orient their position relative to the terrain, as for example when maneuvering to enter a valley.

* The narrower the field-of-view, the more difficult it became to fly the aircraft in a terrain avoidance profile. Depth perception degraded as the field-of-view became smaller.

* The ability to move the head to obtain a wide field-of-regard is necessary to fly terrain avoidance on Visual Route VR 1757 under VFR conditions.
The juxtaposition of ridge-lines provided valuable clues for estimating distance and altitude. When two or more ridge-lines were visible, the perceived motion of the nearer ridge-line relative to the further ridge-line was used to estimate terrain clearance over the nearer ridge. When only one ridge-line could be seen against the sky, both pilots immediately accomodated by comparing a "spot" on the windscreen with the ridge-line.

* Both pilots never put their heads or eyes down into the cockpit.

* Terrain following was relatively easier to fly as compared to terrain avoidance over Visual Route 1757. All five evaluated visual fields-of-view could be flown in a fixed HUD or head-agile mode for terrain following.

* Training, i.e., experience gained after each pass, proved to be beneficial for position orientation to enable the next maneuver to be anticipated.

* The perceptual set of generic geographic and cultural cues such as tree sizes, road widths, ridge contours, vehicle sizes, is very important in providing distance cues.

* Since this flight test was conducted with true binocular vision of the "real-world", the effects of viewing a single synthetic electro-optical scene with both eyes while flying terrain avoidance is unknown. This situation must be evaluated by some type of experimental laboratory apparatus.

* The degredation experienced in viewing ability through different sized apertures was most dramatic when transferring from the 30 to the 20-degree field-of-view.

* Both pilots judged that if they absolutely had to, they might be able to fly a 30-degree field-of-view sensor-coupled vision display provided that they could freely swivel their heads and that the sensor resolution was adequate.

* There was a tendency to fly lower than intended with binocular vision as the visual field-of-view was reduced. This was the opposite effect experienced when flying with monocular vision which created a tendency to estimate altitude lower that it really was.

* Both pilots overestimated altitude as the fields-of-view were decreased in size.

* With narrower fields-of-view replicating a fixed HUD, both pilots tended to unconsciously rotate their head vertically upward to see into the turn and to gather more depth perception cues. When they realized that they were doing this and concentrated on not rotating their head, they tended to scan their eyes up and down in the vertical plane in an attempt to achieve the same effect.

* Extreme difficulty was experienced with fields-of-view smaller than 40-degrees in finding and following narrow valleys. Several turns were missed because the pilot's field-of-view was too small to enable him to visually discern

valley entrances and to anticipate turns.

* The vertical field-of-view was considered to be as critical as the horizontal. This was especially true for the narrower fields-of-view.

* There was a tendency to unconsciously descend in a turn when flying with fields-of-view smaller than 40-degrees.

* With visual fields-of-view narrower than 40-degrees, the pilots tended to fly close along either wall of a valley using the side of the valley to provide peripheral cues. This obviously made it more difficult to anticipate turns into the opposite side of the valley. This tendency is much like a person groping his way along the wall of a dark corridor.

* Cloud shadows on the ground can be misleading when vision is restricted by narrow fields-of-view. When flying with the 20-degree field-of-view, one of the pilots thought that a cloud shadow on a hillside was the entrance into the valley through which he wanted to go. This was so misleading that he had to be alerted by the other pilot who was acting as safety pilot, that he was about to fly into the mountain. By the time he visually acquired the entrance into the real valley, he missed it and had to pull up and overfly the ridge.

* When trading-off resolution versus distance cues provided by haze, i.e., distant hills are more hazy than closer ones, the pilots would rather have sensors capable of providing high resolution of distant ridges attenuated by haze.

* As the visual field-of-view is reduced, there was a tendency to start a turn too late which resulted in the necessity to pop-up over a ridge instead of being able to stay within the valley.

* Narrow fields-of-view, especially 20-degrees, created a tendency to execute overly abrupt climb maneuvers. This was apparently due to the inability of the pilot to accurately estimate distance to ridge-lines.

* A disconcerting loss of aircraft attitude reference was experienced when pulling up over a steep ridge-line at a high climb angle so that all that could be seen forward through the windscreen was sky. This almost bordered on vertigo.

* If the sensor gimbal is to be slaved to an eye-tracker, as for the SCVS concept, sensor lag (high resolution scene lag within the wide field-of-view display) is expected to be a critical problem. This observation refers to the Bright-Eye concept which is discussed in the next section of this paper. One of the pilots expressed concern that vertigo might be

induced by such a lag.

* Flying with a wingman or a larger strike element can be expected to create severe problems in coordinating tactics and avoiding mid-air collisions. Situational awareness is expected to be a real problem.

* Insect splatter on the windscreen is a problem as shown in figure 2-5.

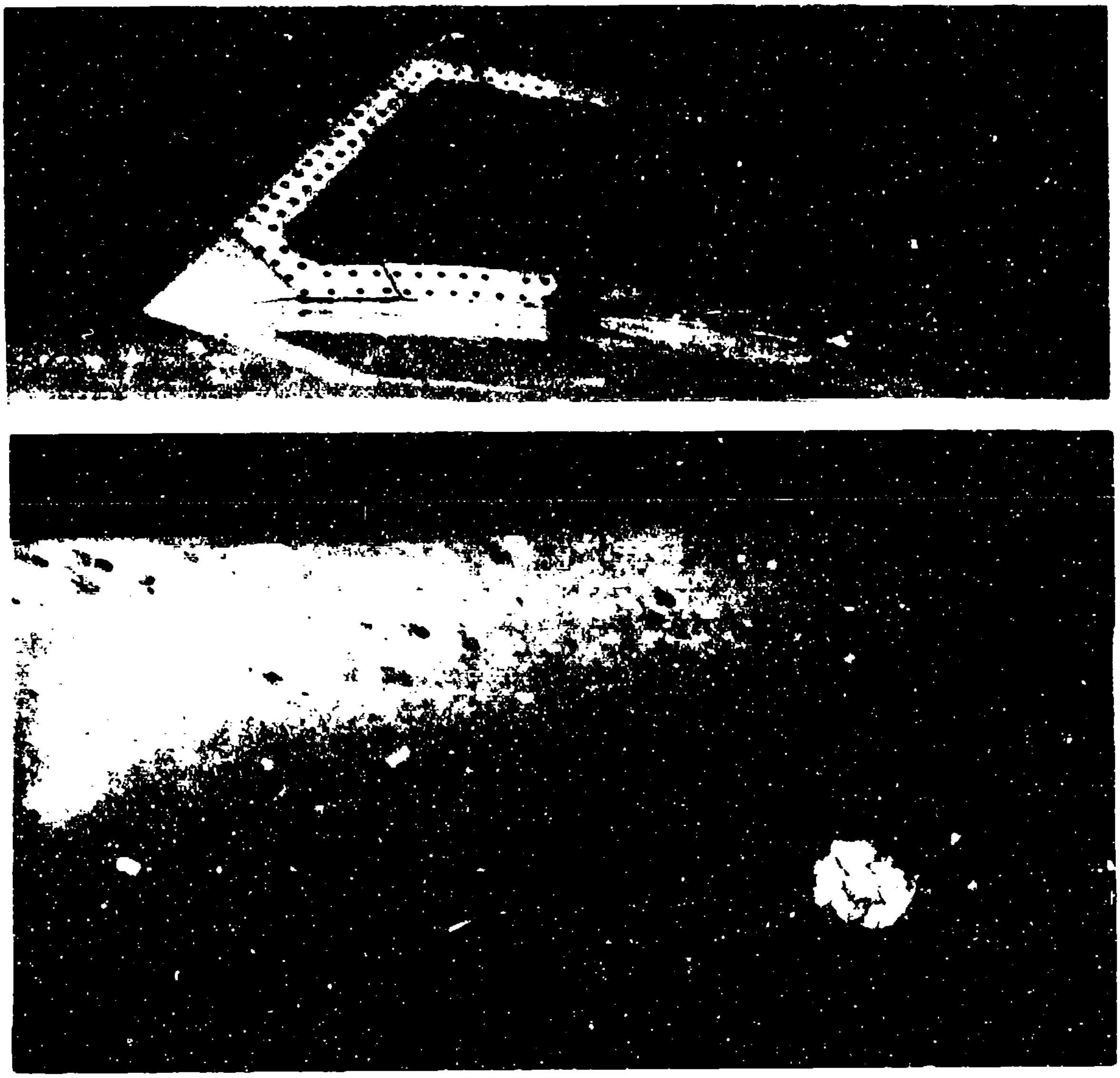

Figure 2-5 Insect Splatter on the Aircraft

3. SENSOR-COUPLED VISION SYSTEMS

The results of the SCVS flight tests indicated the need for a sensor-display combination that provided the widest possible field-of-view and high resolution. Since sensor resolution degrades as field-of-view increases, the only way to achieve this capability is to integrate a wide and narrow field-of-view optical train to provide a composite scene image. The Bright-Eye concept was conceived by the Westinghouse Defense and Electronics Center as a solution.

In addressing the Bright-Eye concept, it is first necessary to understand the characteristics of the human eye. The retina of the eye is sensitive to radiant energy within the visible spectrum, which having been refracted by the lens, forms an inverted image falling upon the retina. Light-sensitive neural receptors in the retina called rods and cones convert the inverted image into nerve impulses which are carried by the optic nerve to the brain. The sensitivity of the retina to light is dependent upon the amount of light falling upon the rods and cones. The fovea which is a small area of the retina providing high resolution contains only cones which are sensitive to red, green, and blue light and increase in sensitivity about sixty times as a function of decreasing light level. The rods, which are most sensitive to green, increase in sensitivity more than 25,000 times as a function of decreasing light level. In dim light, vision is primarily generated by the rods which are color blind but are especially sensitive to detecting movement within the field-of-view of the eye.

The visual acuity of the human eye is very high within the fovea area of the retina within a field-of-view of 1.5 to 2-degrees, but drops off rapidly as a function of the angle off-axis from the fovea so that at around 20-degrees, visual acuity is very low as shown in figure 3-1.

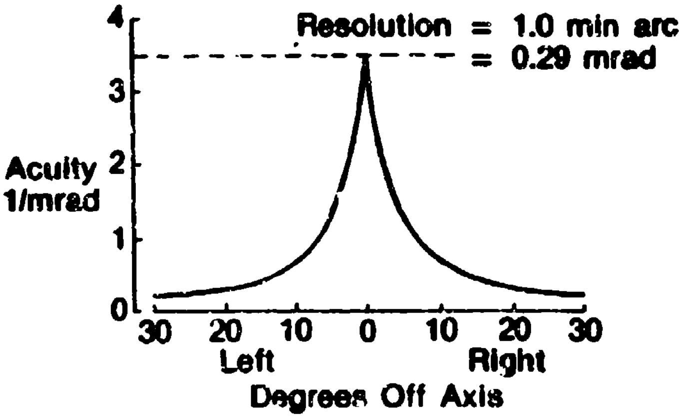

Figure 3-1 Visual Acuity of the Human Eye

However, the eye-brain combination compensates for this loss in acuity by continuously rapidly scanning the eye about the scene. Rather than constant or uniform scanning motions, the eye normally fixates at points for about 0.3 seconds and then moves extremely rapidly to a new fixation point. This resolution characteristic of the eye is demonstratable by a very simple procedure. While looking at and fixating on a single character on this printed page, it is impossible to resolve and read another character four or five spaces away. Peripheral vision also provides extremely critical cues that provide orientation of the spatial relationship of the physical world as visually perceived by the human. For example, it is very difficult if not impossible to maintain a sense of balance or to move about without peripheral vision. However, humans can move about very easily with the foveal vision occluded using peripheral vision only. The series of Westinghouse flight tests conducted during 1981, determined that a visual field-of-view of 40-degrees with full head movement was the absolute minimum required to fly the aircraft. This minimum was considered to be hazardous and did not include target search and acquisition as a part of the test.

The acuity of electro-optical sensors such as television or infrared is a function of field-of-view. To achieve a wide sensor field-of-view that emulates the peripheral vision of the human eye, resolution must be sacrificed. Conversely, if a high resolution that is compatible with the foveal vision of the eye is provided, then the wide sensor field-of-view must be reduced. Contemporary electro-optical imaging sensors rely upon an optical zooming technique to achieve both a high and low resolution image. However, a penalty is paid since the high and low resolution images can only be sequentially displayed causing the observer to lose a sense of orientation within the scene area surrounding a high resolution image. Therefore it makes sense to conceive an electro-optical sensor system providing two integrated fields-of-view as shown in figure 3-2.

The high resolution field-of-view may be centered within and coupled to the low resolution field-of-view so that they move together with the gaze-angle of the eye or the wide field-of-view may be fixed or controlled by some other means and the narrow field-of-view is decoupled and is free to move around within the wide field-of-view as controlled by eye movement. This combination provides the effect of perceiving a high resolution image throughout the wide field-of-view while retaining a peripheral field with a resolution consistent with the peripheral retinal acuity of the eye. A very considerable base of knowledge, hardware, and experience exists with respect to the design and application of helmet-mounted displays in airborne systems. However, this

knowledge base has not yet been extended to encompass the overall system concept of Bright-Eye to ground-based systems. Therefore, the purpose of this research activity is to validate this system concept with strong emphasis being placed on the consideration of the human-systems design aspects.

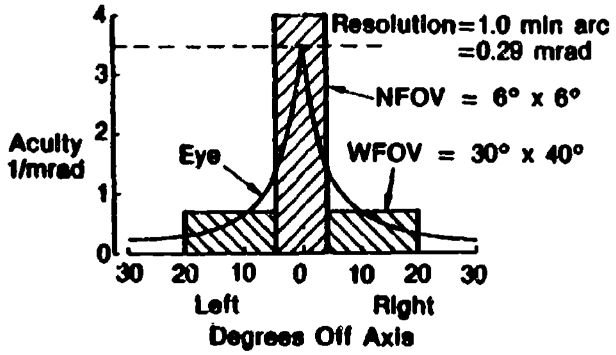

Figure 3-2 Composite Sensor Fields-of View

Laboratory simulations and experiments are being planned to evaluate human performance and acceptance of the system since these are of fundamental importance. Every effort in the proposed program must be measured in terms of its contribution toward achieving this acceptance. A feasibility demonstration consisting of a laboratory and hardware breadboard was initiated by Westinghouse during 1981. Although rudimentary in form and capability, the demonstration breadboard was sufficient to enable many human-systems aspects to be subjectively evaluated. The demonstration breadboard consisted of a 5-degree field-of-view, high resolution TV camera developed by Westinghouse for the USAF Pave Spike weapon delivery pod which was coupled to a commercial 40-degree field-of-view TV camera. A common servo-gimballed mirror provided a common boresight for both cameras. A 5-degree window in the 40-degree field-of-view camera was blanked out and the high resolution video was inserted in its place. The combined video was then displayed via a 1-inch CRT developed by the Westinghouse Tube Division at Elmira, N.Y.. An oculometer was designed and developed to provide the eye-tracker function. The oculometer incorporated a near-infrared LED coupled with a quadrant tracker to illuminate the rear of the pupil by reflected light from the retina. While the 1-inch CRT used for the demonstration did not provide the narrow field-of-view resolution required for an operational system (405 TV-lines versus a minimum of 1000 TV-lines required), it

was considered adequate to demonstrate the concept.

A functional block diagram of the laboratory apparatus is shown in figure 3-3.

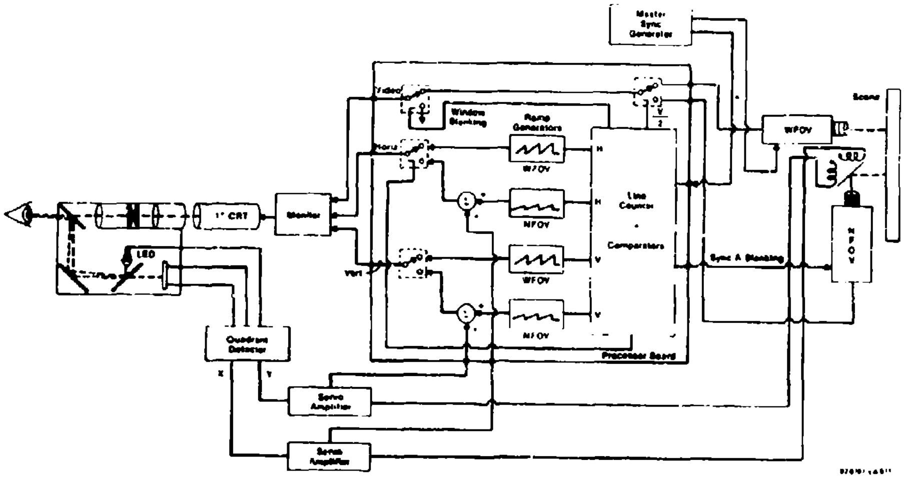

Figure 3-3 Functional Block Diagram of the Bright-Eye Concept

Figure 3-4 shows the laboratory apparatus demonstration hardware.

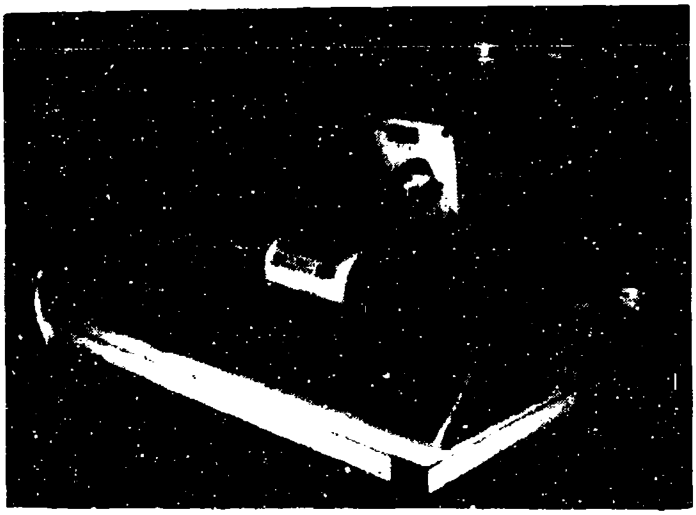

Figure 3-4 Bright-Eye Laboratory Demonstration Hardware

Examples of CRT displays of composite video display scene are shown in figure 3-5.

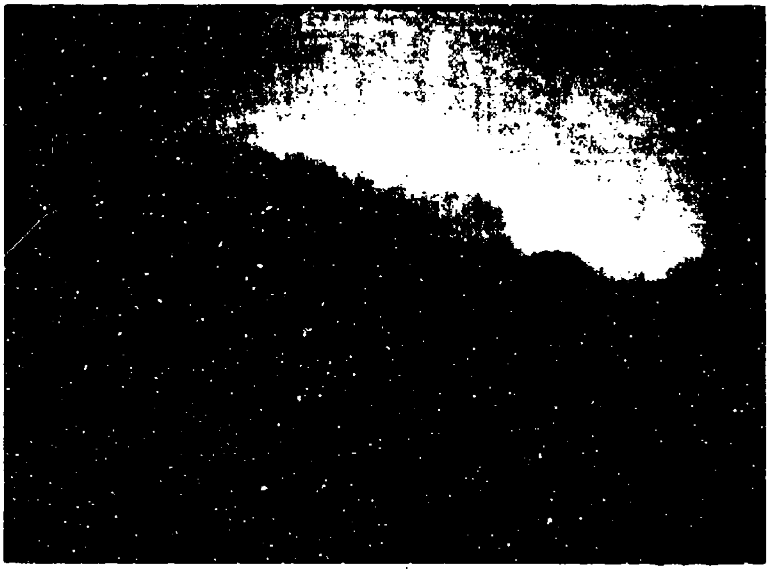

Figure 3-5 Examples of Composite Video CRT Displays

In addition to demonstrating the feasibility of the concept, the laboratory breadboard provided a means to determine the requirements for certain critical experiments prior to defining the criteria for an optimum system. In particular, high agility, servoed control of the narrow field-of-view is required to close the loops for control of the narrow fields-of-view by the eye tracker. A detailed and comprehensive task outline has been prepared to guide the experimental evaluation of system uncertainies, including: 1) coupling of the Bright-Eye display to eye movement via an oculometer and eye-tracker, 2) the parameters of eye movement under the various influences present in the environment for Bright-Eye application, 3) consideration and evaluation of the variables involved in dual visual field-of-view integration, 4) multi-dimensional display and real-world scene registration, and 5) investigation of possible system configurations applicable to more advanced versions of Bright-Eye such as stereoscopic presentation and display magnification. The detailed treatment of these topics has progressed according to priorities based on their significance to the developmental process, first, to bridge informational lacuna that might impede development and, secondly, to treat those issues whose resolution serves to enhance the developmental process. Among the issues of primary concern to the successful development of an effective Bright-Eye system are those concerned with the inevitable temporal disparity, however slight, in narrow field-of-view positioning. In saccadic eye movement, the eye accelerates to as much as 40,000-degrees/second/second, attaining a velocity of 400 to 600-degrees/second. Servo systems that are capable of attaining accelerations greater than 20,000-degrees/second/second are beyond the state-of-the-art. Therefore there is a possibility that this temporal disparity will affect the user in some, as yet unknown way. The Air Force Aeromedical Laboratory has indicated that this issue is one of crucial concern.

The weight and validity of the issue of the eye movement temporal disparity within the narrow field-of-view rests upon the quality of visual perception following saccadic eye movement. The experimental literature pertinent to the subject is in conflict on this issue. One point of view, based on the interpretation of experimental results, holds that perception is intact at the end of the saccade. Another position, equally as experimentally based, suggests that there is a period of perceptual latency, perhaps to the extent of 100 to 150 msec, following an occular saccade.

There are differences in the experimental procedures that might account for the differences in results. If there is a period of perceptual latency, the delay in the narrow field-of-view presentation, provided that it falls within the

100 usec or so time period after a saccade, would be insignificant. Since this issue has been determined to be of major significance, and review of the relevant literature does not provide for its resolution, it must be resolved experimentally. More than one experimental approach may be used to settle this issue. One approach is to design an experiment that will allow the quality of perception following a saccade to be mapped for the full duration of the interval. The results would be of both theoretical and practical value. An experimental procedure of more practical emphasis involves the use of various psychological procedures that result in the determination of the temporal threshold for perception following a saccade. It is possible to identify the point of just-noticeable-difference (JND) for a delayed narrow field-of-view presentation after each saccade. In this approach, the subject defines the point at which a delay in presentation becomes perceptible. It is precisely this point that must be met by servo movement in the Bright-Eye system.

The environment considered for the application of the Bright-Eye concept has been for high performance military aircraft flying terrain following and avoidance (TF/TA) flight profiles at night or during bad weather. Given the demands of the flight environment, it remains for the pilot to adapt to them to the extent that the probabilty of mission success is high and his personal safety reasonably assured. In adapting to the demands of this task, it is expected that the pilot will modify to some degree, his ocular movements to conform to these demands, thereby increasing the efficiency of visual information acquisition processes. The modifications may include reduced head movement since it is dramatically slower and less stable than eye movement, greater saccadic excursions, reduced fixation time, and modified criteria for evaluation and identification of possible targets. Beyond the pilot's adaptive modifications, there are environmental variables that have a greater likelihood of modifying eye movements, as for example, the presence of g-forces concomitant with TF/TA maneuvers. These environmental conditions and pilot adaptations to them set the specific minimum operational requirements for the Bright-Eye system as applied to helmet-mounted displays. The range of values for these variables can only be estimated since a search of the literature has not revealed any applicable research activity.

Variations of the SCVS concept have also been installed in a cockpit simulator and experiments are planned to continue to develop advanced pilot-cockpit interfaces as shown in figure 3-7.

Figure 3-7 Westinghouse SCVS Cockpit Demonstration

4 CONCLUSIONS

In the quest to advance the state-of-the-art of human-systems interaction techniques, care must be exercised not to become enthralled with unique but impractical developments. It is quite probable that no single device will ever prove to be superior for all applications. The same probability holds true for displays. The CRT is expected to be around for many more years although it will have higher resolution and other improvements such as better colors, reduced depth, 3-dimensions, etc.. Predictions into the future are always perilous and therefore none will be addressed here except to say that applications for new concepts and discoveries seem to rely more upon serendipity rather than organized endeavors to identify specific applications. Changing priorities caused by the impact of program requirements requires flexibility and adaptibility in developing innovative display and control techniques.

The sensor-coupled research has evolved into other areas of application. Among which are the use of eye-tracking and voice control to interact with computer-driven displays via an oculometer, eye-tracker, and voice control module. This effort has been successfully demonstrated in the Westinghouse cockpit simulator previously shown in figure 3-7 as well as interfaced with an Apple IIe as shown in figure 4-1.

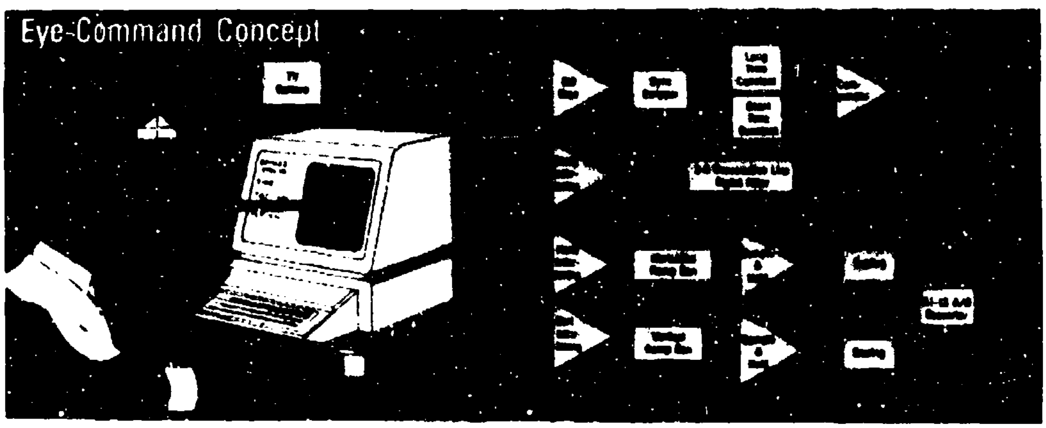

Figure 4-1 Eye-Command Control of Computer-Driven CRT Cursor

This application which has been named Eye-Command to distinguish it from the Bright-Eye concept promises improved human-systems interactions for both military and industrial operations. In addition, the concept can serve as an aid for communication by quadriplegics or persons suffering from severe neurological and/or physiological disorders that make manual, vocal, or sign language communication difficult or impossible. It is also conceivable that the concept could be coupled with robots or automated work stations to provide biofeedback-like functions.

Another spin-off was a program funded in January, 1984 by the U.S. Army ARMCCOM DRDAR-SCF-IM(D), Dover, New Jersey 07801 entitled "Rifleman Eye Movement Study". The objective of the study was to collect data on the eye-movements of the combat rifleman as he sights in his target and fires his weapon, and to analyze the data to determine if identifiable patterns of eye movement were exhibited . A second objective was to determine if anticipatory ocular motions occur just prior to the discharge of the weapon. The study was conducted with the aid of the U.S. Marine Corps who provided the range, weapons, and riflemen at the U.S. Marine Corps Weapons Training Battalion, Quantico, Virginia. The study resulted in the acquisition of significant data which is expected to lead to the development of techniques to improve marksmanship. Figure 4-2 shows a photograph of a rifleman firing an M-16 while fitted with an oculometer.

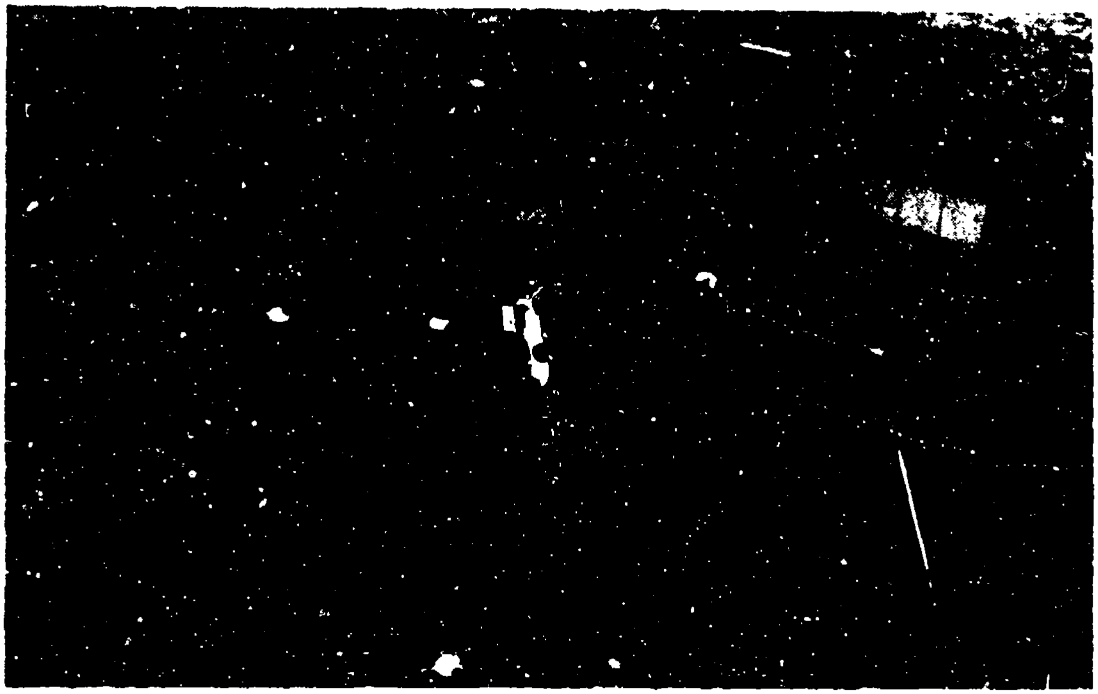

Figure 4-2 Rifleman Firing M-16 While Wearing Oculometer

A third application was the interest generated at the Westinghouse Water Reactor Division, Pittsburgh, for using eye-blink detection eyeglasses to monitor the alertness of nuclear power plant operators. Eye-Blink detection eyeglasses were developed as a spin-off of the Eye-Command concept. These eyeglasses incorporate a LED emmitter and a detector to detect the occurrance of eyeblinks. The original objective was to provide a means for severely handicapped people to communicate with computers. As humans start to drowse off, the duration of time that the eye remains closed during each blink is indicative of the reduced activity of the brain and therefore could serve to alert a control room supervisor or some type of automatic sensing process that the operator was approaching a state of drowsiness.

The use of muscle-induced or brain-evoked electrical potentials to provide control inputs to computers are other techniques being investigated by Westinghouse. A direct physiological coupling between humans and computers can be accomplished through the detection of electrical potentials that occur during the contraction of certain elements of muscles. These potentials are then modulated into signals which are converted from analog into digital impulses for input into a microprocessor which controls CRT display cursor x-y deflection or an electro-optical gimbal system.

The use of advanced human-systems interaction techniques such as addressed in this paper is of special interest for continued human operation in environments contaminated by nuclear, biological, or chemical (NBC) environments and severe climatical conditions such as winter and arctic operations. During these conditions, personnel must wear various types of protective garments which because of their bulkiness, makes it very difficult, and in many cases, impossible, for humans to operate controls.

And finally, no contemporary paper can be complete without reference to artificial intelligence (AI). Westinghouse interest in robotics and AI goes back to the early 1930's when Westinghouse designed and constructed a number of automatons including Electro that could walk and talk and could discriminate between the colors red and green. Electro also had a robot dog that could also walk. Westinghouse is applying AI, expert systems, and knowledge engineering techniques to the design and development of advanced military systems. Many areas of concern are being addressed such as the inflexibilty of AI to respond to the dynamics of tactical decision-making. Since the real-world is exception-driven, unpredictable variables can be expected to occur which has a major impact on AI driven systems. Perhaps the importance of flexibility and adaptibility can best be summed up by this

quotation from Karl Von Clauswitz;

> Since all information and assumptions are open to doubt, and with chance at work everywhere, the commander continually finds that things are not as he expected.

Where does all of this lead us ? When will computers take on the attributes of human beings? Perhaps the answer can be summed up by;

When you permit your daughter to marry one.

AN ARGUMENT FOR STANDARDIZATION IN MODERN AIRCRAFT CREW STATIONS

Vincent Devino
Team Leader

Advanced Crew Station Technology
Grumman Aerospace Corporation

Abstract

Modern avionic systems and display capabilities provide crew station designs with unparalleled flexibility in the manner in which information is presented to the aircrew. In the headlong rush to incorporate these technologies, we seem to be losing sight of the important role standardization has played in improving flight safety and in reducing procurement and support costs. Current design standards do not reflect lessons learned or capabilities made possible by technological advances over the past ten years and are badly in need of revision or replacement.

Technological advances, both existing and on the horizon, such as artificial intelligence, voice command, electronic instrument panels, and automation in general, will offer the designer even more options in formatting and locating information presented to the aircrew. If completely unrestrained, this flexibility will, in the not too distant future, result in a massive and expensive training transition problem and will adversely impact flight safety, vehicle procurement, and support costs. Thus, perhaps more than ever, attention must be focused on the role standardization is to have in the design of future crew stations.

This paper presents background on the history of some present standards, illustrates the lack of adherence to them, and presents arguments in favor of increased emphasis on the standardization of future crew station designs.

Introduction

Before a case can be made for aircrew station standardization, an understanding of why and how it originally came into being may prove helpful (particularly for those of us who weren't around then). For this reason, and because the author believes that history is about to repeat itself, this paper begins with an historical perspective on crew station standardization.

Historical Perspective

During the late 1940s and early 1950s, particularly during the transition from propellers to jets, the operational and safety communities within the armed services became increasingly aware that the lack of standardization was contributing to a very poor accident rate history. Aircrews made the transition from one make and model of aircraft to another largely by reading the flight manual and perhaps by passing a blindfold check in the cockpit. The format and content of the flight manuals themselves were largely determined by the individual aircraft manufacturers. There were no Naval Aviation Training and Operational Procedures (NATOPS), no commonly accepted standard arrangement of flight instruments, no standards for the placement of controls, no requirements for shape coding of various secondary controls (such as those for flaps and landing gear), and no standards for relating the direction of the control motion to its effect on the aircraft performance or the position of the device operated by the control. Given enough time, the crewman simply adapted to the cockpit configuration and quirks of the aircraft he was currently flying and usually experienced no difficulty.

However, when difficulties arose or the crewman became complacent, and particularly if he were more experienced, he often reverted to old habits which sometimes produced disastrous results. During a sudden encounter with instrument flight rules (IFR) conditions, the instrument scan pattern he had developed after many hours in an older aircraft suddenly had to be relearned because the panel arrangement of the new aircraft was different. In another instance, when he reached for where he instinctively knew the flap handle was, he got the gear handle which usually resulted in gear retraction during rollout after a landing; or, when he moved a fuel selector valve in the direction he was accustomed to for selecting an auxiliary tank, the fuel was turned off in the new airplane.

Another intriguing variation was the short-lived difference in attitude indicator presentations. In some aircraft it was outside-in, i.e., the horizon was fixed and the miniature airplane moved with respect to it in pitch and roll; in the majority of other aircraft, it was inside-out (present case), i.e., the miniature airplane is fixed and the horizon line is free to move. Another frequently found variation was in the bank angle presentation. In some cases the indicator moved opposite to the direction of turn; in others it moved in the direction of the turn.

In recognition of the problems created by such situations as well as the impact that standardization could have on reducing costs and increasing utilization of increasingly complex aircraft, DOD in 1951 established what is now known as the Aircrew Station Standardization Panel (ASSP). Make-up of ASSP eventually included Air Force, Navy, and Army members; NASA, FAA, and industry representatives served in an advisory capacity. The ASSP effort produced most of the crew station design standards which exist today. The civilian counterpart of ASSP, the Society of Automotive Engineers Cockpit Standardization Committee performed a similar service for commercial aviation.

As the standardization effort matured and gradually bore fruit, the ASSP met with decreasing frequency in the 1970s and then became virtually dormant from June 1980 to 1983. Thus, during the years in which some of the most explosive growth in crew station technologies took place, the ASSP's activity and involvement with this growth was, and continues to be, at an ebb.

Is Standardization Still Needed?

Some might argue that the need for standardization is no longer as pressing as it once was in view of current and future operating policies which call for very extensive and formalized transition training, and which reduce the frequency with which aircrew are apt to change to different aircraft. Another argument is that reduced numbers and models of aircraft being procured do not warrant the effort involved in standardization. Yet another frequently heard contention is that development of new standards would be counter to the present trend toward deregulation.

The author's reply to these arguments is that the essential reasons for standardization (safety of human life, preservation of valuable equipment, and cost reduction in both design and procurement) are overriding and that the crew station of the future requires standardization as much as, if not more than, those of the past.

The flexibility inherent in many present and certainly all future "glass cockpits" presents us with the strong possibility of both inducing large expenditures in manpower and dollars to develop new configurations and, conversely, unparalleled opportunities for cost reduction through standardization.

Increases in development costs will arise as a result of the flexibility in display format and location within the crew station afforded us by modern avionics/display systems. The trend is clearly toward automated display management and multifunction displays. These capabilities plus the advent of integrated flight and thrust management, integrated flight/fire control systems, etc., provide a crew station design team with a bewildering array of choices in both display format and location. Extensive analytical and simulation efforts will be required to arrive at an acceptable configuration. The software required will correspondingly grow in complexity and cost. Software development will probably be the largest cost driver in future crew station design. How then, will the design team make the decisions necessary to establish a safe and manageable crew station configuration?

One answer is through the application of appropriate human engineering analysis and testing techniques. Depending upon mission requirements and aircraft complexity, this can be a long and expensive undertaking. Why not reduce the magnitude of this task to some extent by standardizing format and location of at least the basic information required to fly the airplane: airspeed, altitude, attitude, and heading/course? Can performance variations among aircraft of a particular configuration and mission type (i.e., fixed wing fighters) be so great as to warrant differences in where and how this information is displayed?

The author does not believe so. But, an examination of current and proposed electronic displays for basic flight information reveals a wide variation in formats, from replication of existing "boiler gages" to 3-D analog displays, as shown in Figure 1.

Likewise, a comparison of the displays in various operational aircraft with each other and with the requirements of MIL-STD-884C, as shown in Figure 2, reveals many variations and departures from its requirements.

The other solution is to simply place things in the crew station as they were in the preceding airplane design. This approach could be considered a form of standardization in its simplest interpretation. This method tends to perpetuate mistakes. In the case of future aircraft, it will result in unnecessarily large and expensive crew stations.

A new safety consideration brought on by the automation which makes "glass cockpits" possible is software quality control. Despite all the component and systems redundancy designed into modern aircraft, it is believed that the picture tubes will occasionally go blank, more than likely from a software glitch rather than a hardware failure. One way to minimize the likelihood of such occurrences is to minimize the number of iterations required to produce software used for basic cockpit displays.

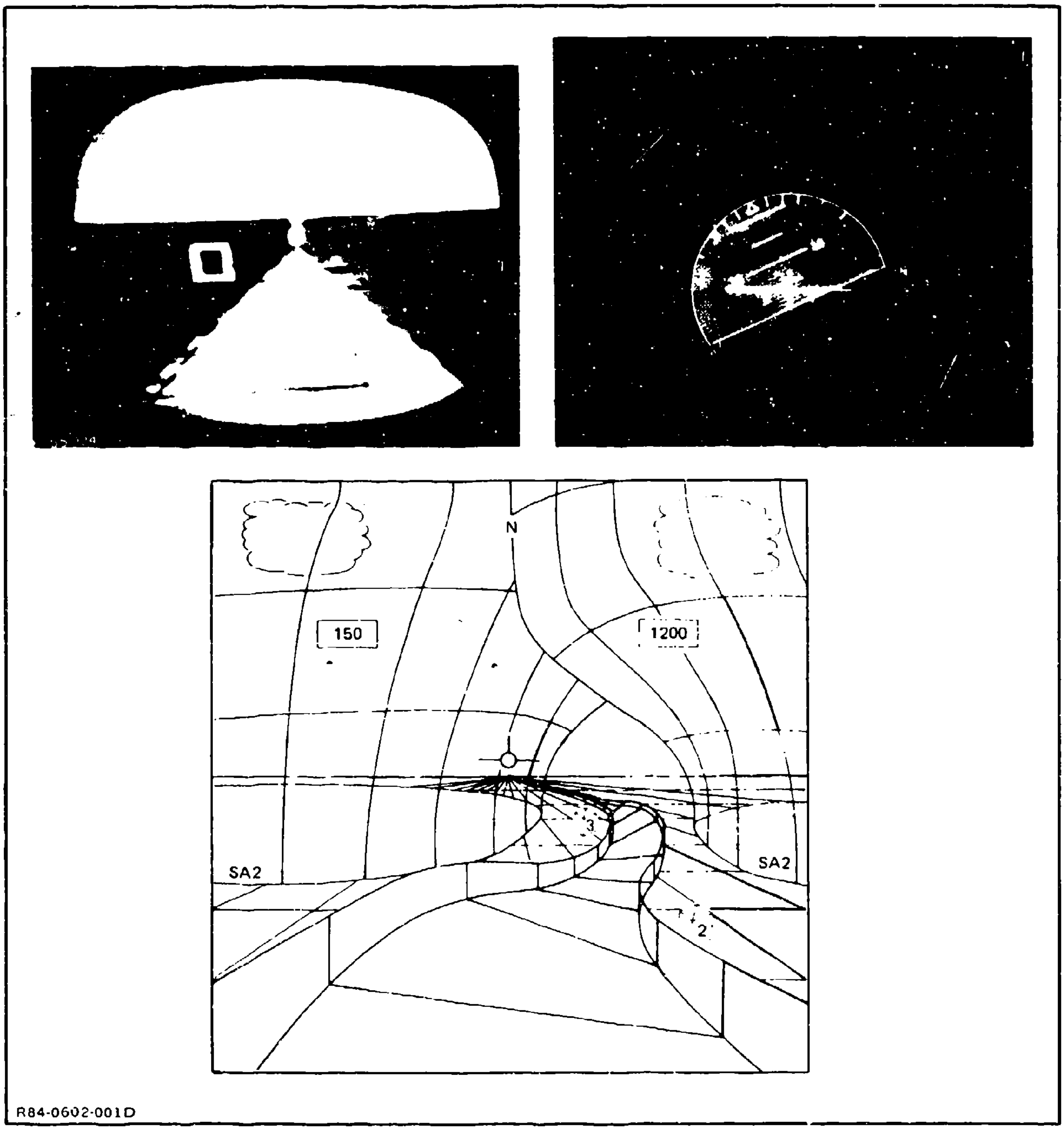

Fig. 1 Current & Proposed Electronic Flight Information Displays

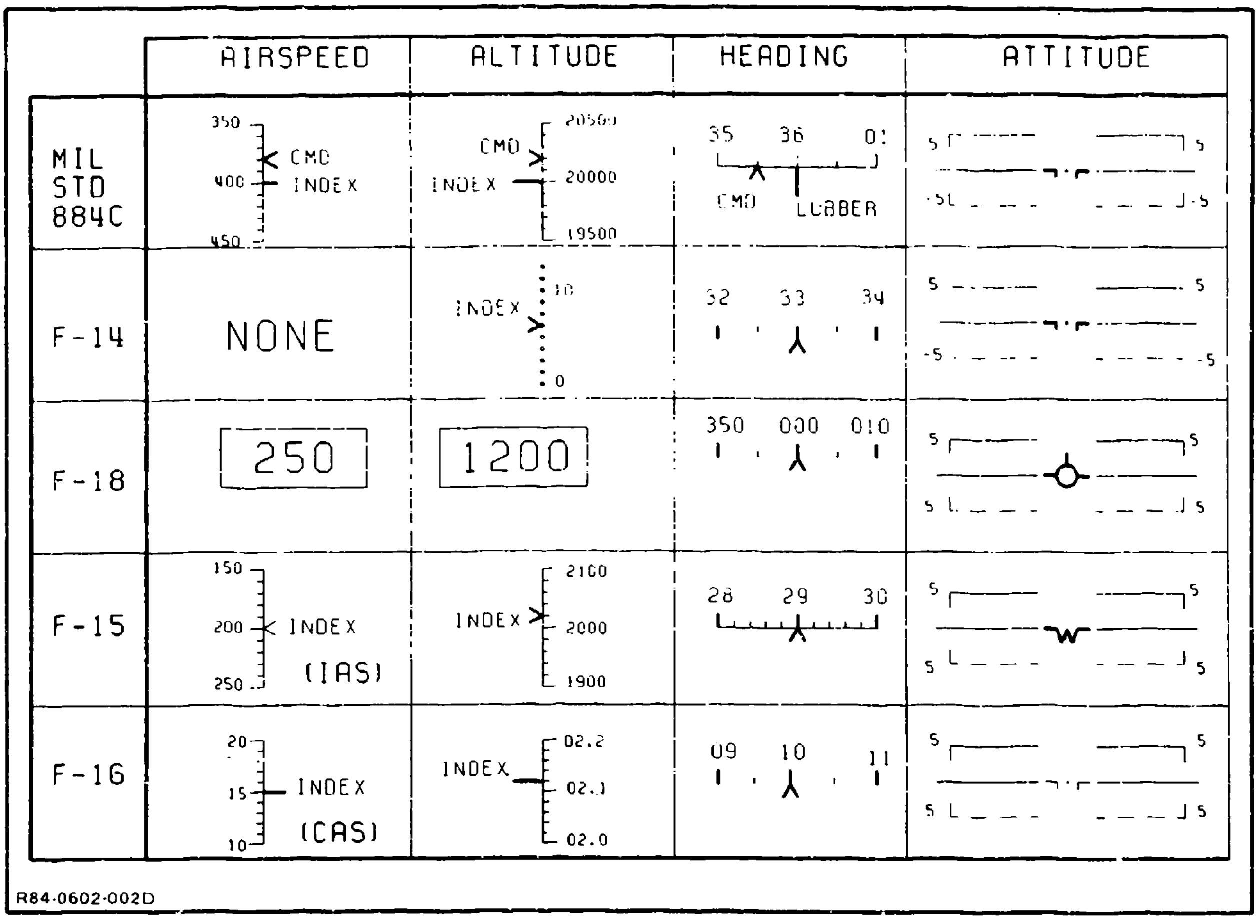

Fig. 2 Symbology Comparison

Impacts on Software

As mentioned previously, software development is now a significant safety and cost factor in the development of a new aircraft and will become even more so in the future. Standardization could help to reduce software costs by:

- Reducing or eliminating much of the repetitive effort which goes into developing and substantiating display symbology for each new make and model of aircraft
- Increasing commonality of software for driving flight displays, training devices, and support equipment.

An attempt by ASSP to standardize electronically generated displays in the late 1960's resulted in the publication of MIL-STD-884. It was last revised in 1972 (MIL-STD-884C) and, as is apparent by a review of Figure 2, there have been many deviations from it. MIL-STD-884 needs to be thoroughly revised or replaced with a new standard which reflects the knowledge gained in display symbology and formatting since 1972. While this effort is ongoing, consideration should be given to standardizing weapons delivery symbology. Table 1 lists some possible candidates for standardization; some of these are included in MIL-STD-884C.

TABLE 1 SYMBOLOGY STANDARDIZATION CANDIDATES

HORIZON
AIRSPEED
ALTITUDE
ANGLE OF ATTACK
VERTICAL VELOCITY
PITCH ANGLE
BANK ANGLE
RATE OF TURN
SLIP/SKID
VELOCITY VECTOR
HEADING
COURSE
WAYPOINT
WEAPON AIMING/RELEASE
– GUNS/BULLET TRAJECTORY
– I/R MISSILES
– RADAR MISSILES
– TV
– BOMBS/BOMB TRAJECTORY
– ROCKETS
– TIME/TO RELEASE/UNTIL IN RANGE/CLOSURE RATE
– LAUNCH ENVELOPE
– TARGET DESIGNATOR
– ALLOWABLE STEERING ERROR
– ETC
ACCELERATION
OWN AIRCRAFT

R84-0602-005D

In addition to the above, existing standards need to be revised and/or new standards need to be established for both information location and display arrangement as illustrated by Figures 3 and 4. The same can be said for several other existing standards which have been very much a part of any crew station design consideration.

- MIL-STD-203 - Aircrew Station Controls and Displays - Assignment, Location and Actuation of, for Fixed Wing Aircraft
- MIL-STD-250 - Aircrew Station Controls and Displays for Rotary Wing Aircraft
- MIL-STD-411 - Aircrew Station Signals.

All of the above are woefully out of date when viewed in light of present practices in the industry. An effort to accomplish this task was begun by ASSP at their meeting in June, 1983.

Any standards developed must consider not only what is, but also the aircraft systems which will be operating in the year 2000 in order to avoid creating a massive training transition problem. Much research has been accomplished, and there are many programs such as the USAF Advanced Systems Integration Demonstrations (ASIDS) and Microcomputer Applications of Graphics and Interactive Communications (MAGIC), which currently are addressing such avionics systems and display issues. These programs must be closely monitored, and the results obtained must be incorporated into the standards as appropriate.

By the same token, the author realizes that total standardization is neither feasible nor desirable since nonstandard formats will need to be developed to meet technological changes and tactical requirements. However, much could be accomplished by the standardization of flight and tactical displays.

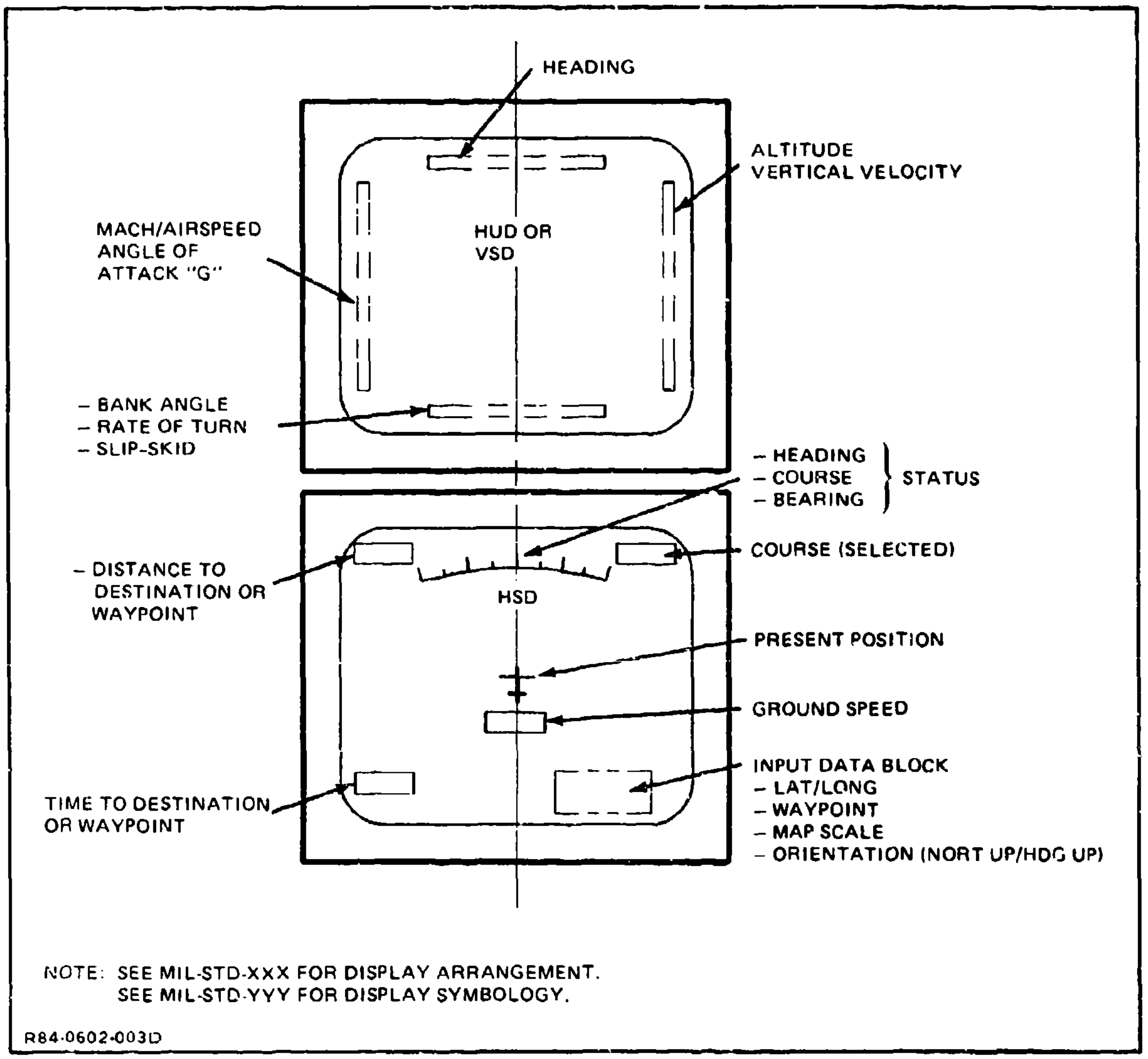

Fig. 3 Information Location Standard (Example)

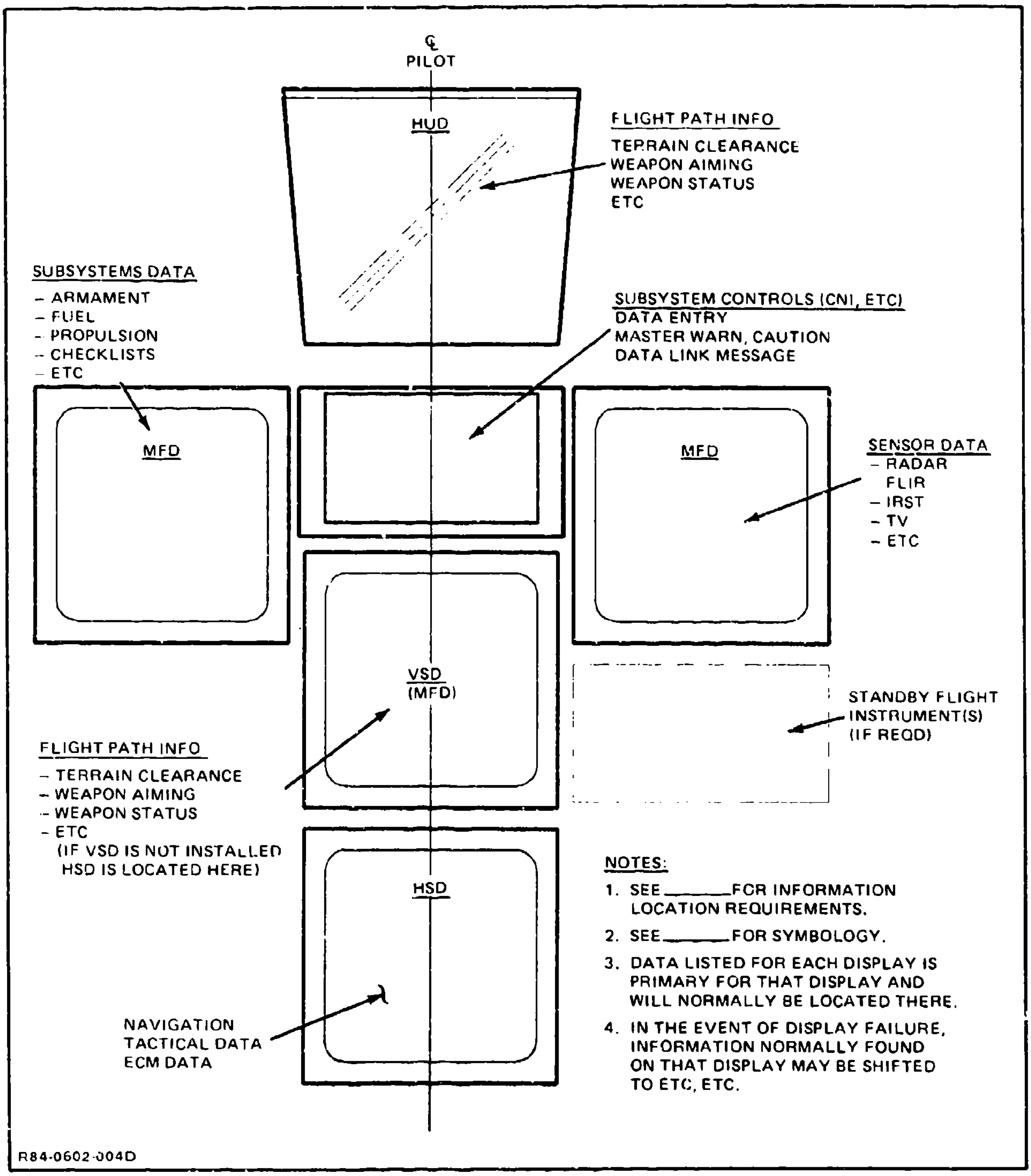

Fig. 4 Display Arrangement & Information Location Standard (Example)

Conclusion

If for no other reason, potential cost savings should drive DOD toward renewed emphasis on standardization. It does not take much imagination to recognize the benefits which could accrue from the standardization of flight information formats, symbology, and display locations and, conversely, the chaos which could ensue in the absence of standardization.

The mechanism required to achieve this goal already exists in the form of the ASSP. ASSP's primary thrust would be to bring about agreement on interservice standards for display size, location, and formats. Industry should participate through the Aircraft Industries Association (AIA) to assist ASSP in the development of the necessary standards.

The choice is clear. We can continue to allow standardization to drift at the expense of flight safety and program cost or we can grasp the potential that new technology offers: true standardization on an interservice basis with benefits to both safety and cost.

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LIST OF ATTENDEES

Samuel A. Abbate
Systems Software Engineer
Grumman Aerospace Corporation
Bethpage, NY 11719

Terence S. Abbott
Aerospace Engineer
NASA-Langley Research Center
Hampton, VA 23665

Ray Abraczinskas
MKTG MGR
Lear Siegler Instrument Division
4141 Eastern Ave., S.E.
Grand Rapids, MI 49508

Eugene C. Adam
Staff Manager-MDC Fellow
McDonnell Douglas Corporation
P.O. Box 516
St. Louis, MO 63166

William J. Adams
Supervisor-Human Eng./Biomed
Rockwell International
2210 W. 180th Place
Torrance, CA. 90504

CAPT Raoul Alvarez, USN
Deputy Director Plans and Requirements
DMAAC Attn: PR
3200 S. 2nd St.
St. Louis, MO 63118

James R. Andres
Tech Specialist
USAF ASD/ENACI
Wright/Patterson AFB, OH 45433

Harold Andrews
NAVAIRSYSCOM
Tech Dir, R&T (AIR-03A)
Navy Department
Washington, DC 20361

L. E. Apprill
Staff Engineer
Lockheed California Company
1048 E. J-5
Lancaster, CA 93535

Howard Arnoff
Naval Air Systems Command
AIR-5313
Washington, DC 20361

B.R. Ashworth
NASA-LARC
M.S. 125B
Hampton, VA 23606

Werner Ast
Loral Information Display Systems
6765 Peachtree Industrial Blvd.
Atlanta, GA 30360

James C. Bach
Electrical Engineer
Naval Avionics Center
6000 E. 21 B/825
Indianapolis, IN 46218

Claud N. Bain
Consultant
2846 Maple Lane
Fairfax, VA 22031

Bart H.D. Bakker
Dutch Airline Pilot Association
Charlotte van Montpensierlaan 2A
Amstelveen, Holland 1181 RR

Herb L. Bansbach
Director Marketing-Government
Litton Aero Products Division
26540 Agoura Road
Calabases, CA 91302

Glen Barone
Sales Engineer
AEG-Telefunken Corporation
Rt. 22-Orr Dr.
Somerville, NJ 08876

L.B. Barraza
Flight Simulation Engineer
Northrop Corporation
8900 E. Washington
Pico Rivera, CA 90603

D.A. Bayless
Project Engineer
NAVAIR
Washington, DC 20361

Judith E. Beck
Engineering Assistant
Westinghouse
Box 746
Baltimore, MD 21203

Sam Bello
Raytheon Company
465 Centre St.
Quincy, MA 02169

Robert M. Beggs
Human Factors Engineer
Boeing Vertol
P.O. Box 16858 M/S P 32-18
Philadelphia, PA 19142

J. Bentz
Manager, Marketing Avionics/Electronics
McDonnell Douglas Electronics Company
P.O. Box 426
St. Charles, MO 63301

Russell Berthot
Project Engineer
NAVAIR
8410 Berwick Rd.
Marlton, MD 20772

Gene G. Bianchi
Engineer
Kaiser Electronics
2701 Orchard Park Way
San Jose, CA 95134

Frank Bick
Engineering Psychologist
U.S. Army AVSCOM
6108 Wanda
St. Louis, MO 63116

Dr. Carole Bohn
Engineering Psychologist
IBM
P 70 Mail Drop 0906, FSD
Owego, NY

G. Wayne Booker
Sales Engineer
General Electric
50 Fordham Rd
Wilmington, MA

Dean Bomrer
MKTG Manager
Rockwell Int.
RR1
Toddville, IN 52314

Paul J. Boyle
Marketing Director
Northrop Corporation
One Northrop Ave.
Hawthorne, CA 90250

William A. Breitmaier
NAVAIRDEVCEN
Aircraft & Crew Systems Tech. Dir.
Code 6022
Warminster, PA 18974

Frank J. Brem
Section Mgr, Advanced Systems Dev.
Sundstrand Data Control, Inc.
Overlake Industrial Park
Redmond, WA 98052

Gary D. Brodersen
Section Head, Integrated Instr.
& Display
NAVAIR
5404 Water Crest Ct.
Fairfax, VA 22032

J. Richard Brown
Consultant
Kaiser Electronics
4416 Elan Pl
Annandale, VA 22003

Stanley Burg
Corporate VP & Division Gen. Manager
GTI Corporation, Computer Graphics Div.
10060 Willow Creek Rd.
San Diego, CA 92131

Malcolm Burgess
Mgr. ATOPS Program
NASA Langley Research Center
Mail Stop 265
Hampton, VA 23665

Joseph C. Byram, Jr.
Marketing Manager
Allied Bendix Aerospace Sector
1000 Wilson Blvd., 30th Floor
Arlington, VA 22209

Luiz M. Cabral
Electrical Engineer
Naval Underwater Systems Center
Code 3512, Bldg. 1171/1
Newport, RI 02841

G.J. Calderone
Grumman Aerospace Corporation
M.S. B67-01
Bethpage, NY 11714

J. Robert Caldow
Mktg. Mgr. (USA)
Smiths Industries
1225 Jefferson Davis Hwy, Suite 402
Arlington, VA 22202

Robert Carrol
President
Systems Associates, Inc.
7750 Dagget St.
San Diego, CA 92111

Dr. Carter
2207 N. Utah St.
Arlington, VA 22207

Floyd M. Cassidy
MICRO SWITCH
1766 Old Meadow Land
McLean, VA 22102

C.D. Catoe
Aircraft Design Engineer, Sr.
Lockheed-Georgia Company
85 S. Cobb Drive, Dept. 72-09
Marietta, GA 30063

Stan Chaffee
Electronics Engineer
USAF ASD/ENASI
Wright/Patterson AFB, OH 45433

Thomas E. Chapman
Senior Engineer
DCS Corporation
Rt. 2, Box 492
Hollywood, MD 20636

Peter Chapola
Consultant
CMC Electronics, Inc.
Suite 600, Rm 630
1225 Jefferson Davis Hwy
Arlington, VA 22202

Charles T. Chartier
Unit Manager Display Systems Sales
General Electric Company
P.O. Box 5000, Room 155
Binghamton, NY 13902

Maureau Claude
Project Manager
Thomson-CSF2 Gannett Dr.
White Plains, NY 10604

Paul C. Clements
Code 7590
Naval Research Lab
Washington, DC 20375

A.B. Close
British Embassy
3100 Massachusetts Ave., N.W.
Washington, DC 20008

Paul H. Cleveland
Avionics Engineer
LTV Aerospace & Defense
P.O. Box 225907 M/S 194-50
Dallas, TX 75265

Albert J. Cloutier
Raytheon Company
465 Centre St.
Quincy, MA 01269

John J. Cockburn
Navigation Systems Department
Ferranti
Silverknowes
Ferry Road
Edinburgh, EH4 4AD Scotland

Dr. Danny Cohen
USC/ISI
4676 Admiralty Way
Marina del Rey, CA 90292

Dick Cohen
Surv. Adv Displays
Dept. 7411 MC 2/3
Flight Systems Div.
Teterboro, NJ 07608

John J. Connelly
Head, Optics & Display Group
Grumman Aerospace Corporation
Engineering, Mail Stop B28-35
Bethpage, NY 11714

CAPT C.W. "Bill" Connor, Ph.D.
Delta Air Lines/ALPA/BET
1722 Ponce De Leon Blvd.
Coral Gables, FL 33134

David R. Cocke
Grumman Aerospace Corporation
Swan Pond Rd., Mail Stop B19-07
Calverton, NY 11933

Kent Cornell
Ex. Dir. Mktg.
Kaiser Electronics
2701 Orchard Pk Way
San Jose, CA 95134

MAJ Marcus A. Cox
U.S. Army Human Engineering Lab
Aberdeen Provings Grounds, MD

William J. Cox
President
Aviation Systems Concepts, Inc.
7011 Evergreen Ct.
Annandale, VA 22003

Victor Cronauer
Systems Associates, Inc. of CA
1911 J. Davis Hwy.
Suite 1006 CMI
Arlington, VA 22202

Benjamin C. Cruickshanks
Manager
Weapons Control Systems Engineering
General Electric Company
Room 688, P.O. Box 5000
Binghamton, NY 13902

Vincent Devino
Team Leader
Grumman Aerospace Corporation
Mail Stop C31-05
Bethpage, NY 11714

Lou Cusimano
Operations Inspector
Federal Aviation Admin
800 Independent Ave., S.W.
Washington, DC 20591

Arthur E. Dieball
Mktg. Rep.
JET Electronics & Technology, Inc.
5353 52nd St.
Grand Rapids, MI 49508

Ron Dahl
GRP LDR CREW SYS
Grumman Aerospace Corporation
A-6E Upgrade Program
M/S A12-040
Bethpage, NY 11714

David J. Dilks
Royal New Zealand Air Force
Embassy of New Zealand
37 Observatory Circle NW
Washington, DC 20008

Gardner Davis
Sr. Engrg Specialist
Vought Aero Products Div., LTV
1338 Carriage Dr.
Irving, TX 75062

Ed Drumheller
Senior Engineer
Northrop Aircraft (DEPT. 3020/92)
One Northrop Ave.
Hawthorne, CA 90250

J. Larry DeCelles
WOXOF, Ltd.
9107 Lee Blvd.
Leawood, KS 66206

Jerry L. Duchene
Supv. Electronic Eng.
USAF/ASD/ENASI
Wright/Patterson AFB, OH 45424

Donald DeMyer
Marketing Mgr.
Lear Siegler, Inc., Instrument Dir.
4141 Eastern Ave, S.E.
Grand Rapids, MI 49508

Lefebvre Du Prey
Thomson-CSF DPP/AVS
178 Bd Gabriel Peri
92240 Malakoff, France

Ed Denta
Group Leader/Project Eng.
Smiths Industries, Inc
14180 Roosevelt Blvd.
P.O. Box 5389
Clearwater, FL 33518

Ken Dyson
Pilot
Rockwell NAAO
Box 38
Edwards, CA 93523

COL Dan Eliason
Air Force Human Resources Lab(AFSC)
Brooks AFB, TX 78235

R. Thad. Elliott, III
ALPA
930 Canterbury Rd.
Atlanta, GA 30324

Bill Emo
New Product Planner
MICRO SWITCH
11 West Spring St.
Freeport, IL 61032

J.D. Englehart
McDonnell Douglas
P.O. Box 426
St. Charles, MO 63301

LT. Micheline Y. Eyraud
Naval Safety Center
Code 95
NAS Norfolk, VA 23511

Howard Faecher
Manager, Weapons System Engineering
Westinghouse Electric Corporation
P.O. Box 746, Mail Stop 1715
Baltimore, MD 21203

D.D. Fairchild
Mktg. Mgr.
Honeywell
1744 Jefferson Ave.
St. Paul, MN 55105

James F. Farrell
Project Engineer-Displays
Litton Systems Canada LTD
25 Cityview Dr.
Rexdale Ont. Canada M9W5A7

Leagh Farrell
Test Pilot
Canadian Dept. of Transporation
32 Thare Cres. Nepean
Ontario, Canada K2J2P4

Donald Fassel
Manager, Business Development
Sundstrand Data Control, Inc.
Overlake Industrial Park
Redmond, WA 98052

Dr. Lew Feaster
HQ AVSCOM
ATTN: DRSAV-NS
4300 Goodfellow Ave.
St. Louis, MO 63120

RADM E.L. Feightner, USN (RET)
Hunt Enterprises, Inc.
2009 N. 14th St., Suite 101
Arlington, VA 22201

Peter A. Fleury
Marketing Manager
Kaiser Electronics
2701 Orchard Parkway
San Jose, CA 95134

John N. Fendley
Engineering Test Pilot
Westinghouse Electric Company
BWI Airport-Box 746, M.S. 506
Baltimore, MD 21203

Kenneth E. Fersch
Marketing Mgr.
Sundstrand Aerospace
100 Wilson Blvd, Suite 2400
Arlington, VA 22209

Stephen M. Filarsky
Project Engineer
NAVAIRDEVCEN
Warminster, PA 18974

Robert H. Fischer
Program Manager
Grumman Aerospace
Pt. Mugu, CA 93042

John Gailhard
Sr. Engineer
Norden Systems
P.O. Box 5300
Norwalk, CT 06856

Gerald J. Fox
Grumman Aerospace Corporation
M.S. B25-35
Bethpage, NY 11714

Edward S. Garami
Principle Engineer
Northrop Corporation
8900 East Washington Blvd, T540/90
Pico Rivera, CA 90660

Ms. Robert Fox
State University of NY at Stony Brook
4 Mystic Ct.
Stony Brook, NY 11790

Dr. David D. Garber
Member, Research Technical Staff
Northrop Research & Technology
One Research Park
Palos Verdes Peninsula, CA 90274

James R. Francis
Sr. Research Analyst
Northrop
20759 Missionary Ridge
Walnut, CA 91789

Jerry Gard
Ex. Director Advanced Systems
Kaiser Electronics
2701 Orchard Park Way
San Jose, CA 95134

Lee R. Fredrickson
Senior Engineer
Sikorsky Aircraft
N. Main St.
Strattord, CT 06601

R.A. Gardner
Sr. Eng. Human Factors
Bell Helicopter, Textron
2908 Ridgewood Dr.
Hurst, TX 76054

COL Luther L. French, U.S. Army
DOD Liaison to FAA
FAA
8622 Burlingwood Dr.
Springfield, VA 22152

Karen Garner
Aircrew Systems Branch (SY722)
Systems Engineering Test Dir.
NATC
Patuxent River, MD 20670

E.V. Fretwell
Deputy Director-Operations Engineering
& Air Satety Department
Air Line Pilots Association
1625 Massachusetts Ave., N.W.
Washington, DC 20036

G.N. Garrett
Sr. Tech Engineer
Northrop Corporation
Dept T321/90
8900 Washington Blvd
Pico Rivera, CA 90660

Nicholas J. Furio
Engineer
Sperry Electronic Systems
Lakeville Rd, MS E-2
Great Neck, NY 11020

George H. Gaughan
Marketing Manger
Cardion Electronics
Long Island Expressway
Woodbury, NY 11797

Peter Gibson
Ferranti
2300 M. St., N.W. #800
Washington, DC 20037

Ricky L. Greth
Essex Corporation
65 West Street Rd.
Suite C-200
Warminster, PA 18974

Ray L. Gillespie
Mgr, Aerospace
General Electric
3 Penn Center Plaza
Philadelphia, PA 19102

Robert W. Griffin
Mgr, Marketing & New Business
Kollsman Instrument Company
220 Daniel Webster Hwy
Merrimack, NH 03054

James D. Gilmour
Mgr., Crew Systems Technology Staff
Boeing Military Airplane Company
Mail Stop 41-08, P.O. Box 3707
Seattle, WA 98124

Kenneth E. Grosgebauer
Lead Engineer
General Dynamics Corporation
P.O. Box 748, MZ 2141
Fort Worth, TX 76101

Claude R. Giraud
Thomson CSF
178 Bld Peri
92240 Malakoff France

John W. Grubb
Royal Australian Air Force
Embassy of Australia
1601 Massachusetts Ave., N.W.
Washington, DC 20036

LT COL David G. Girling
Assistant Canadian Forces Air Attache
Canadian Defense Liaison Staff
2450 Massachusetts Ave., N.W.
Washington, DC 20008

Marty Gunther
Tech. Staff Specialist
Kaiser Electronics
2701 Orchard Park Way
San Jose, CA 95134

Gerald Givens
Senior Systems Engineer
Marconi Avionics, Inc.
4500 North Shallowford Rd.
Atlanta, GA 30338

Tom Gwynne
Test Pilot
Grumman Aerospace Corporation
Swan Pond Road B-1907
Calverton, NY 11933

Glen Glasell
Engineer
Northrop
10453 Artesia Blvd.
Belltower, CA 90706

Carol Hahn
Division Military Mktg. Division
Hughes Aircraft Company
1655 El Camino Real
Carlsbad, CA 92008

Richard Goodman
Design Engineer
Grumman Aerospace Corporation
Mail Stop C31-05
Bethpage, NY 11714

Oliver E. Hall
Hd, Nav & Inst. Br.
NAVAIR
AIR-5495
Washington, DC 20361

Dr. Bruce Hamilton
Human Factors Engineer
Sikorsky Aircraft
North Main St.
Stratford, CT 06601

John Hammerstrom
Engineering Test Pilot
Grumman Aerospace
Mail Stop B02-04
Bethpage, NY 11714

John P. Hanish, Jr.
Systems Software
Grumman Aerospace
C01-31T
Bethpage, NY 11714

Thomas D. Hanna
Engineering Psychologist
NAVAIRDEVCEN
Warminster, PA 18974

Donald C. Hanson
Boeing Commercial Airplane Company
P.O. Box 3707 M/S 47-08
Seattle, WA 98124P

Gerald E. Harstine
Mktg. Manager
Lear Siegler, Inc.
4141 Eastern Ave., S.E.
Grand Rapids, MI 49058

Robert T. Hayes
Manager, Military Mktg.
JET Electronics & Technology
5353 52nd St., S.E.
Grand Rapids, MI 49508

Mark Hayler
Royal Australian Air Force
Embassy of Australia
1601 Massachusetts Ave., N.W.
Washington, DC 20036

D.W. Helgeson
Rockwell

H.G. Heininger
Consultant
Sperry Corporation, Flight Systems
4554 Lawnvale Dr.
Gainesville, VA

John F. Hendric on
Program Manager
FAA/APM-430
800 Independence Ave., S.W.
Washington, DC 20591

David M. Herbine
Electronics Engineer
NAVAIRDEVCEN
Warminster, PA 18974

Sam Herron
Senior Engineer
General Dynamics
P.O. Box 748 M22270
Ft. Worth, TX 76101

Fritz Hjelte
Professor
Royal Institute of Technology
Department of Aeronautics
S-100 44 Stockholm Sweden

Roy Holmes
Software Manager
Marconi Avionics, Inc.
1375 Kettering Tower
Dayton, OH 45423

George W. Hoover
Systems Associates of CA.
746 Alma Real Drive
Pacific Pallisades, CA 90272

Lawrence B. Ii
Consultant
Larry Ii Systems/Displays/Technology
11430 Harton St.
Manassas, VA 22111

Marsha Ivins
Engineer
NASA JSC CC5
Houston, TX 77058

Arnie D. Jackmond
Director of Marketing Avionics
Management Systems
Teledyne Systems Company
19601 Nordhoff St.
Northridge, CA 91324

J.D. Jahn
Tech Director
AD TECH
Box 425D
Lexington-Park, MD 20653

John E. James
Mktg Manager
Kaiser Electronics
2701 Orchard Parkway
San Jose, CA 95134

Paul C. Jenkins
Senior Systems Engineer
Rockwell International
400 Collins Rd NE MS 124-317
Iowa 52498

Raymond R. Jones
Fellow Engineer
Westinghouse Electric Corporation
P.O. Box 746 Mail Stop 278
Baltimore, MD 21203

James G. Julien
Mech. Systems Engineer
General Electric Company M/Z41
So. Fordham Rd.
Wilmington, MA 01887-2190

Michael Kalmanash
Sr. Display Specialist
Kaiser Electronics
2701 Orchard Parkway
San Jose, CA 95134

David B. Kanaly
Advanced Programs
Astronautics Corp. of America
P.O. Box 523
Milwaukee, WI 53201

James B. Kelly
AST
MS 265 NASA Langley Research Center
Hampton, VA 23665

Allan E. Kelvin, Sr.
Sr. Staff Psychologist
Grumman Aerospace Corporation
Mail Stop B4 Plt 005
Bethpage, NY 11714

Robert Kerle'
Senior Engineer
Sperry Electronic Systems
Lakeville Rd M.S. F-2
Great Neck, NY 11020

LCDR Andrew J. Key, Jr.
U.S. Coast Guard
Commandant (G-EAE)
2100 2nd St., S.W.
Washington, DC

Philip Kiel
Photo-sonics, Inc.
820 S. Mariposa
Burbank, CA 91506

Lawrence P. Killilea
Engineer
NAVWEPCEN (CODE 3144)
China Lake, CA 93555

James L. Kindig
Systems Engineer
Tech Applic. Inc.
1225 Jefferson Davis Hwy #509
Arlington, VA 22202

William J. King
Technology Manager
NAVAIRSYSCOM AIR-310J
Washington, DC 20361

Robert Klach
Program Manager
Lear Siegler Avionic Systems Corporation
7-11 Vreeland Rd.
Florham Park, NY 07932

Richard W. Koepke
Loral Information Display System
6775 Peachtree Industrial Blvd
Atlanta, GA 30360

L.L. Kohnhorst
Supervisor, Flight & Fire Control
Rockwell International Corporation
4300 E. Fifth Ave.
Columbus, OH 43216

T. Richard Lee
Electronics Engineer
NAVAIR
3719 Venzry St., N.W.
Washington, DC 20016

David H. Larkin
Mktg. Rep.
JET Electronics & Technology, Inc.
Crystal Plaza 1, Suite 306
2001 Jefferson Davis Hwy
Arlington, VA 22202

MAJ G. Dennis Leslie
Canadian Defense Liaison Stall
2450 Massachusetts Ave., N.W.
Washington, DC 30063

Chris Lewis
Mechanical Engineering MGR
Marconi Avionics, Inc.
4500 N. Shallowford Rd.
Atlanta, GA 30338

Arno Linder
Electronic Engineer
Commander/AVRADA
ATTN: SAVAA-F (A. Linder)
Fort Monmouth, NJ 07703

J. Kenneth Longmuir
Principal Engineer
Boeing Commercial Airplane Company
830 97th Ave, S.E.
Bellevue, WA 98004

Dr. Stephen J. Lukasik
Vice President & Manager
Northrop Research & Technology
One Research Park
Palos Verdes Peninsula, CA 90274

Walter A. Lunk
Mktg. Mgr.
Fairchild Weston Systems, Inc.
300 Robbins Lane
Syosset, NY 11791

Joyce Madden
Engineering Psychologist
NAVAIR
AIR-5313G, Room 948, J.P. 2
Washington, DC 20361

Gerald S. Malecki
Office of Naval Research Code 442
800 N. Quincy St.
Arlington, VA 22152

Teresa Mann
Associate Aircraft Engineer
Lockheed-Georgia Company
86 South Cobb Dr.
Marietta, GA 30063

George Marrett
Marketing
Hughes Aircraft
22727 Ticonderoga Rd.
Woodland Hills, Ca 91364

Joe McInturff
Staff Engineer
Lockheed Georgia
3260 Clearview Dr.
Marietta, GA 30060

Roy Martin
Engineering Test Pilot
Northrop Aircraft Division
P.O. Box 278
Edwards AFB, CA 93523

W.H. McMillen
President
MACM Corporation
P.O. Box 627
Plumsteadville, PA 18949

Dale Masbruch
Manager, Intra-Corp Marketing
JET Electronics & Technology
5353 52nd St., S.E.
Grand Rapids, MI 49508

J.P. McVicker
FAA APM-430
800 Independence Ave.
Washington, DC 20591

John C. May
Consultant-Avionics Systems
General Electric
French Rd MD 286
Utica, NY 13503

William Metzger
Sr. Des. Eng
General Electric AID
50 Fordham Rd.
Wilmington, MA 01887

Elmer A. McBride
Repr-Navy Prog
General Electric Company
1331 Pennsylvania Ave, N.W.
Suite 860 Washington, DC 20004

Anthony D. Miller
Marketing Manager
Sperry Corporation, Flight Systems
P.O. Box 9200
Albuquerque, NM 87119

Chuck McAfee
Senior Staff Specialist
Kaiser Electronics
2701 Orchard Parkway
San Jose, CA 95134

Robert V. Miller
USN Test Pilot School
NAS Patuxent River. MD 20670

Hugo W. McCauley
Head, Human Factors Engineering
Douglas Aircraft Company
3855 Lakewood Blvd., Code 35-36
Long Beach, CA 90846

Robert V. Mills
Manager, SMS
Fairchild Communications
20301 Century Blvd.
Germantown, MD 20874-1182

LT COL John W. McDermott
Candian Defense Liaison Stall
2450 Massachusettes Ave., N.W.
Washington, DC 20008

Kenneth Mitchell
MKTG. MGR. Flight Deck Displays
Smiths Industries
St. Petersburg/Clearwater Airport
P.O. Box 5389
Clearwater, FL 33518

Heber G. Moore
HQ Naval Material Command
MAT08D4
Washington, DC 20360

T.A. Morgenfeld
Lockheed California Company
22041 Covello St.
Canoga Park, CA 92138

Jim Morrisette
Human Factors Engineer
Essex Corporation
P.O. Box 517
Fort Rucker, AL 36362

John Moylan
Group Head-Crew System
Grumman Aerospace Corporation
Bethpage, NY 11714

W.G. Mulley
Project Director
NAVAIRDEVCEN
Code 602B
Warminster, PA 18974

Robert A. Murphy
Engineer
Westinghouse Electric Corporation
N.S. 154 P.O. Box 746
Baltimore, MD 21203

Leon J. Neisius
Sales Manager
CONRAC
803 Aspen Rd
New Carlisle, OH 45344

Lanny Nerbovig
Boeing
16414 SE 35
Bellevue, WN 98008

Dave Newecerk
Engineer
NAVAIR
Crystal City

Richard L. Newman
Crew Systems Consultant
P.O. Box 481
Yellow Springs, OH 45387

Dean Nicholson
Sr. Product Specialist
MICRO SWITCH
11 W. Spring St.
Freeport, IL 61032

Dr. Michael D. Olinger
Lear Siegler , Inc./Instrument Div.
4141 Eastern Ave., S.E.
Grand Rapids, MI 49508

Joseph G. Oliver
Air Line Pilots Association
1625 Massachusetts Ave., N.W.
Washington, DC 20036

Keith O'Toole
Design Engineer
Kaiser Electronics
2701 Orchard Park Way
San Jose, CA 95134

Alan Parker
Computer Scientist
Naval Research Lab
Code 7592
Washington, DC 203754

David R. Parker
Northrop
8900 E. Washington Blvd.
Pico Rivera, CA 90606

John W. Parker III
General Engineer
NAVAIRDEVCEN
Code 6022
Warminster, PA 18974

Jerry B. Polin
Human Factors Engineer
NAVAIRDEVCEN
Code 6022
Warminster, PA 18974

Charles A. Parlier
Experimental Test Pilot
Hughes Helicopter, Inc.
5000 E. McDonell Rd.
Mesa, AZ 85204

Janet Priebe
Grumman Aerospace Corporation
Mail Stop C31-05
Stewart Ave.
Bethpage, NY 11714

Harvey R. Pekich
Section Mgr, Aerospace & Defense
Sales
Sundstrand Data Control, Inc.
Overlake Industrial Park
Redmond, WA 98052

Daniel J. Provine
Senior Engineer
Westinghouse Electric Corporation
P.O. Box 746
M.S. 701
Baltimore, MD 21203

Paul P. Pencikowski
Northrop
8900 E. Washington Blvd
Pico Rivera, CA 90606

George C. Quon
Sales Manager
General Electric
P.O. Box 5000
Binghamton, NY 13902

Norman W. Penney
Military Mktg Mgr
Smiths Industries
Evesham Rd
Bishop's Cleeve, Cheltenham, Glos.
GL52 4SF, England U.K.

Fred Rademacher
Sr. Engr.-Displays & Controls
Grumman Aerospace Corporation
A-6 Program
M/S A12-040
Bethpage, NY 11714

Lee Person
Research Pilot
NASA LARC
Hampton, VA 23665

R.C. Raece
Sr. Marketing Representative
Sperry Corporation, Flight Systems
P.O. Box 9200
Albuquerque, NM 87119

E.A. Petrauskas
Manager-Military Systems Sales
General Electric Company
50 Fordham Rd.
Wilmington, MA 01887 M/A 43B

Michael S. Randolph
Advisory Engineer
IBM Corporation
Bodle Hill Road
Owego, NY 13827

Greg Pochapsky
ALPA
3045 Mockingbird
St. Charles, MO 63301

Robert E. Ray
Electronics Engineer
NAVAVIONICCEN
6000 E. 21st Code D/822
Indianapolis, IN 46226

Carole Regan
Computer Scientist
Naval Underwater Systems Center
Bldg 1171/1 Code 3512
Newport, RI 02840

Lee Rhinebarger
Avionics Mkt. Manager
Raytheon Company
MW&PT Division
Foundry Ave.
Waltham, Massachusetts 02254

LT COL Haiplik Richard
Postfach 801160, 8000 Munich 80
Germany

Arthur R. Rifkin
Manager, Advanced Navy Program
Grumman Aerospace Corporation
Mail Stop C3105
Bethpage, NY 11714

Daniel D. Riley
Essex Corporation
65 West Street Road
Suite C-200
Warminster, PA 18974

David Roberts
Senior Engineer
Northrop Aircraft (Dept. 3020/92)
One Northrop Ave.
Hawthorne, CA 90250

John M. Robinson
Research Scientist
Teledyne Systems
10ill Casaba Ave.
Chatsworth, CA 91311

Gary L. Robitaille
Marketing Rep
McDonnell Douglas Electronics Company
P.O. Box 560
Colchester, VT 05446

Al Rodgers
Program Manager
Polhemus Nav Sci /MDC
P.O. Box 560
Colchester, VT 05446

John Romer
TID Bldg. 405
Naval Air Test Center
Patuxent River, MD 20670

Stan Roscoe
New Mexico State
Box 5095
Las Cruces, NM 88003

C.E. Rosenmayer
Tech. Specialist
McDonnell Douglas Corporation
P.O. Box 516
St. Louis, MO 63166

Richard Rover
Principal Engineer
Bendix Flight Systems
Lambs Lane
Cresskill, NJ 07626

Myron S. Rubin
Manager, Southeast Region
Raytheon Company
400 Army Navy Drive
Arlington, VA 22202

LCDR John H. Rush
AFC MRAeS TN RTD
Ferranti, Navigation Systems Dept.
Silverknowes, Ferry Road
Edinburgh, EH4 4AD Scotland

Joseph Samandarov
Litton Systems Canada Limited
25 Cityview Drive
Rexdale Ontario
Canada M9W5AJ

Curtis E. Sandler
Accident Investigator
National Transportation Safety Board
800 Independence Ave., S.W.
Washington, DC 20594

Howard Sherman
Team Leader Crew Station Tech.
Grumman Aerospace Corporation
Mail Stop C04-14
Bethpage, NY 11714

Dennis J. Schmuker
Northrop Corp.
7667 Stage Road #94
Buena Park, CA 90621

Mary E. Sherman
Grumman Aerospace Corp.
6 Fuller St.
Dix Hills, NY 11746

MAJ Robert H. Schrimsher
Research Aviator
U.S. Army Aeromedical Research Lab
P.O. Box 577
Ft. Rucker, AL 36362

Karen Sherwin
El. Engineer
NAVAIR
5250 Valley Forge Dr. #316
Alexandria, VA 22304

W. J. Seckel
IBM
MC 1210/D242
1322 Space Park Dr.
Houston, TX 77058

CDR Shultz
F-14D/A6E Upgrade
Naval Air Test Center
Patuxent River, MD 20670

Dr. Rudiger Seifert
Messerschmitt-Bolkow-Blohm GmbH
Military Aircraft Division
P.O. Box 801160
D-8000 Munchen 80

Dr. Louis D. Silverstein
Principle Scientist
General Physics Corporation
1770 The Exchange, Suite 150
Atlanta, GA 30339

Robert D. Seinfeld
Director of Marketing
Astronautics Corp. of America
P.O. Box 523

Joe D. Simmons
Electrical Engineer
SA-41 Mission Systems
NAS Patuxent River, MD 20670

Stephen H. Shelley
Program Manager
Intermetrics, Inc.
733 Concord Ave.
Cambridge, MA 02138

Clifford E. Sisler
Sales Manager
METAVAC, Inc.
45-68 162nd St.
Flushing, NY 11358

A. T. Sherbert
M/S P32-88
Boeing Vertol Co.
P.O. Box 16858
Philadelphia, PA 19142

James A. Skipper
Principle Engineer
Fairchild Industries
20301 Century Blvd.
Germantown, MD 20874-1182

Mark Smith
Research Analyst/Crew Station Dev.
Northrop Corporation
One Northrop Ave.
Hawthorne, CA 90250

George G. Steinmetz
AST
NASA Langley Res Ctn
MS 156 B
LARC, Hpt., VA 23669

Russell Smith
Marketing Manager
Litton Systems Canada Limited
25 Cityview Dr.
Rexdale Ontario Canada

Lorren Stiles
Test Pilot
Sikorsky Aircraft
North Main St.
Stratford, CT 06601

Wayne D. Smith
Mgr Crew Systems Research
Boeing
2929-76th S.E. #412
Mercer Is., WA 98040

Thomas A. Stinnett
Human Systems Lab Mgr
Westinghouse Defense & Electronics
MS 4625 Friendship Site
Box 746
Baltimore, MD 21203

Pieter W. Snyders
Director
Polhemus Navigation Sciences Division
McDonnell Douglas
P.O. Box 560
Colchester, VT 05446

Paul Stringer
ARINC Research Corporation
2551 Riva Rd.
Annapolis, MD 21401

John H. Speicher
Product Manager
Schott Glass Technologies, Inc.
400 York Ave.
Duryea, PA 18642

Tom Suvada
Kaiser Electronics
2701 Orchard Park Way
San Jose, CA 95134

Wade V. Squires
Marketing Mgr- D.C.
Sperry
1725 S. Jefferson Davis Hwy #401
Arlington, VA 22202

J.O. Sweeny, Jr.
Manager-Sales
General Electric Company
50 Fordham Road
Wilmingham, MA 01877 M/A 43B

Robert B. Stack
Naval Flight Officer
Mission Systems
Nas Patuxent River, MD 20670

William A. Sylvester
Managing Director
Gentex Corporation
2824 Metropolitan Place
Pomona, CA 91767

Johnnie L. Stegemoller
General Dynamics, Ft. Worth Div.
P.O. Box 748
Ft. Worth, TX 76101

Stephen P. Taylor
Smiths Industries
P.O. Box 5389
Clearwater, FL 33518

Timothy S. Taylor
U.S. Rep. Airborne Display Div.
Marconi Avionics, Inc.
1375 Kettering Tower
Dayton, OH 45423

CAPT Kenneth E. Thomas, USMC
2nd Marine Aircraft Wing
Fleet Marine Force, Atlantic
Marine Corps Air Station
Cherry Point, NC 28533

Lowell K. Thomas
Project Manager
NAVAIR
AIR 54951B
Washington, DC 20361

Warren Thomas
Mgr. Adv. Program
Northrop Corporation
One Research Park
Palos Verdes, CA

Guice Tinsley
Program Manager
FAA
8415 Thornberry Dr. E.
Upper Marlboro, MD 20772

David Trousdale
ALPA-All Weather Flying Committee
2225 245th Ave., S.E.
Issaquah, WA 98027

Paul Turner
Senior Development Engineer
Honeywell Military Avionics Div.
1625 Zarthan Ave. M.S. 2166
Minneapolis, MN 53440

Ron Turner
Avionics Systems Engr
Lockheed-CA Company
P.O. Box 551, Dept 67-41
Bldg 82B, Plant B-6
Burbank, CA 91520

Robert Vance
Mktg. Mgr.
Fairchild Weston Systems, Inc.
300 Robbins Lane
Syosset, NY 11791

Joyce L. Vander Linde
Mechanical Engineer
Naval Air Engineering Center
Code 9312
Lakehurst, NJ 08733

German Von Thal
McDonnell Douglas Aircraft
3855 Lakewood Blvd.
Mail Code 35-29
Long Beach, CA 90846

Frank Watler
Tech Mgr.
Northrop
5403 W. 142nd Place
Hawthorne, CA 9025090274

K.C. Waugh
Engineering Specialist
General Dynamics
P.O. Box 748
Ft. Worth, TX 76101

Harry Saruszewski
Senior Staff Engineer
Sperry Flight Systems
9201 San Mateo Blvd., N.E.
Albuquerque, NM 87113

William R. Webb
Advisory Engineer
Westinghouse Electric Corporation
P.O. Box 746
Baltimore, MD 21203

J.W. Weber
Hughes Aircraft Company
P.O. Box 92426
Bldg. R1, Mail Stop C320
Los Angeles, CA 90009

M. Weihrauch
Hughes Aircraft Company
P.O. Box 92426
Los Angeles, CA 90009

F.D. Wells
IBM
MC 1210/D236
1322 Space Park Dr.
Houston, TX 77058

R.L. Wernecke
Tech Director
Rotary Wing
NAS Patuxent River, MD 20670

Noreen Wilcox
Engineer
Northrop Aircraft (Dept 3020-92)
One Northrop Ave.
Hawthorne, CA 90250

John Wilde
Engineer
Grumman Aerospace
Bethpage, NY 11714

William J. Wildeman
Senior Engineer
General Dynamics Corporation
P.O. Box 748, MZ 2141
Ft. Worth, TX 76101

Dr. Ronald D. Williams
Technical Staff
MITRE Corporation
Mail Stop W186
McLean, VA 22102

Stephen Williams
Vice President
SFENA Corporation
2617 Aviation Pkwy
Grand Prairie, TX 75051

Dick Windyka
Prog. Mgr.
P.O. Box 619619
DFW Airport, TX 75261-9615

John A. Wise, Ph.D.
Westinghouse R&D Center
1310 Beulah Rd
Pittsburg, PA 15235

Jim Wolverton
Mgr. Targeting Systems
Honeywell
5100 Gambles Dr.
St. Louis Park, MN 55416

Warren L. Worthington
Engineering Specialist
Northrop Corporation
306 S. Eucalyptus Ave.
Ingleweed, CA 90301

Theodore J. Zammitt
Display Group Leader
Simmonds Precision
Panton Rd.
Vergennes, VT 05491